THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE PERMANENT SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant —*Novum Organum*, *Præfatio*.

VOLUME THE EIGHTIETH,

FOR 1924.

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SOLD ALSO AT THE APARTMENTS OF THE SOCIETY,

MCMXXIV.

List

OF THE

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OF THE

GEOLOGICAL SOCIETY OF LONDON.

Elected February 15th, 1924.

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Sir Aubrey Strahan.
Prof. W. W. Watts.
Mr. H. Woods.

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P. 259. line 22 from the bottom. For '*Dibunophyllum vaughani*', read '*Dibunophyllum bourtonense*, nom. nov.'

Dates of Issue of the Quarterly Journal for 1924.

No. 317—March 17th, 1924.

No. 318—July 25th, 1924.

No. 319—October 4th, 1924.

No. 320—December 31st, 1924.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1923–24.

November 7th, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair.

The Names of certain Fellows of the Society were read out for the second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the non-payment of the arrears of their Annual Contributions.

The List of Donations to the Library was read.

The President announced the donation, by the executors of the late Prof. W. Crawford Williamson, of two armchairs, formerly the property of William Smith (1769–1839), and bequeathed by him to John Williamson, of Scarborough.

The following communications were read:—

1. 'On the Skeleton of *Iguanodon atherfieldensis* sp. nov., from the Wealden Shales of Atherfield (Isle of Wight).' By the late Reginald Walter Hooley, F.G.S. (Read by Dr. A. Smith Woodward, F.R.S., F.L.S., F.G.S.)

2. 'The Igneous Rocks of the Tortworth Inlier.' By Prof. Sidney Hugh Reynolds, M.A., Sc.D., F.G.S.

Parts of the skeleton of *Iguanodon atherfieldensis* were exhibited by permission of Mrs. Hooley, in illustration of the paper by the late R. W. Hooley; and specimens of igneous rocks from the Tortworth Inlier were exhibited by Prof. S. H. Reynolds in illustration of his paper.

November 21st, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair.

John Alexander Dunn, B.Sc., Assistant Superintendent of the Geological Survey of India, Calcutta (India); John Reginald Fox, M.Inst.C.E., Jordan Hill, Barnsley; Cecil Evelyn Keep, B.Sc., care of the Attock Oil Company, Ltd., Khaur, Pindigheb, Punjab (India); George Martin Lees, 1 Victoria Road, Rathgar, Dublin; George Gregory Lewis, 23 Steventon Road, W. 12; George Keith Talbot, Stonecroft, Peppard Road, Caversham (Oxfordshire); and Herbert Cubitt Gostling Vincent, B.A., 54 Owlstone Road, Cambridge, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'The Development of the Severn Valley in the Neighbourhood of Iron-Bridge and Bridgnorth.' By Leonard Johnston Wills, M.A., Ph.D., F.G.S.; with a Section on the Upper Worfe Valley, in collaboration with Ernest Edward Leslie Dixon, B.Sc., F.G.S.

December 5th, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President; and, afterwards, Dr. G. T. Prior, F.R.S., F.G.S., in the Chair.

Ajit Kumar Banerji, B.A., A.R.C.S., Geological Survey of India, 106/4 Amherst Street, Calcutta (India); Robert Barnard, 1 Wood Street, Calcutta (India); William Frederick Canning, Bishop Feild College, St. John's (Newfoundland); Donald John Farquharson, M.Sc., c/o W. R. French, La Chaumière, Oberland Road, St. Martin's (Guernsey); William Frederick Fleet, M.Sc., A.I.C., 73 Woodlands Park Road, King's Norton, Birmingham; Leslie Issott Grange, M.Sc., Geological Survey of New Zealand, 38 The Terrace, Wellington (New Zealand); Arthur Hardcastle, Engineer's Office, Newcastle & Gateshead Water Company, Newcastle-upon-Tyne; David Glyn John, M.A., Lynwood, Gowerton, Swansea; Stanley Holmes, M.Sc., Elm Cottage, Killingworth Station (Northumberland); August Perl, B.Sc., 5 Sharon Road, Chiswick, W. 4; Charles Archibald Philip Southwell, B.Sc., Port of Spain, Trinidad (British West Indies); Philip Guy Stevens, 34 Windsor Terrace, Uplands, Swansea; and Leonard George Wilkins, B.Sc., Orchard House, Harbury, were elected Fellows of the Society.

The List of Donations to the Library was read.

Dr. F. A. Bather exhibited, on behalf of Mr. A. S. Hirst, F.Z.S., specimens, microscope-slides, and lantern-slides of Arachnid Remains from the Rhynie Chert, and described their structure and affinities.

The following communications were read :—

1. 'The Geology of the Northern Border of Dartmoor, between Whiddon Down and Butterdon Down.' By Charles William Osman, M.Inst.C.E., F.G.S.

2. 'The Geology of Southern Guernsey.' By Donald John Farquharson, M.Sc., F.G.S.

Rock-specimens and microscope-sections were exhibited by Mr. C. W. Osman, and microscope-sections were exhibited by Mr. D. J. Farquharson, in illustration of their respective papers.

December 19th, 1923.

Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The President announced that the Council had voted a resolution of deep sympathy with the relatives of the late Prof. T. G. Bonney, Sc.D., F.R.S. (Secretary in 1878–84, President in 1884–86), who had been a Fellow of the Society since the year 1860.

The announcement was received by the Fellows present standing.

Prof. William Johnson Sollas, Sc.D., F.R.S., F.G.S., gave a Demonstration of the Method of Investigating Fossils by Serial Sections, illustrated by specimens, photographs, and lantern-slides.

Mr. John Walton, M.A., gave a short lecture on the Investigation of the Nature of Fossil Plants, illustrated by lantern-slides and microscopic preparations.

Prof. Herbert Leader Hawkins, D.Sc., F.G.S., exhibited and commented upon Anatomical Preparations of Fossil Echinoids.

January 9th, 1924.

Prof. A. C. Seward, Sc.D., F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year:—Frederick Noel Ashcroft, M.A., and Horace Woollaston Monckton, Treas.L.S.

The following communications were read:—

1. 'The Geological Structure of the Clevedon–Portishead Area (Somerset).' By Prof. Sidney Hugh Reynolds, M.A., Sc.D., F.G.S., and Edward Greenly, D.Sc., F.G.S.

2. 'The Avonian of the Tytherington–Tortworth–Wickwar Ridge (Gloucestershire).' By Frederick Stretton Wallis, Ph.D., F.G.S.

3. 'The Avonian of the Western Mendips, from the Cheddar-Valley Railway to the Sea, West of Brean Down.' By Miss Agnes Elizabeth Bamber, M.Sc. (Communicated by Prof. S. H. Reynolds, M.A., Sc.D., F.G.S.)

January 23rd, 1924.

Prof. A. C. Seward, Sc.D., F.R.S., President,
in the Chair.

George Florance, Baron Boston, Hedsor Wharf, Bourne End (Buckinghamshire); Oliver Meredith Boone Bulman, B.Sc., Assoc.R.C.Sc., 51 Oakhill Road, Putney, S.W. 15; Major L. Merson Davies, R.A., Kohat (N.-W.F.P.), India; Eileen Mary Guppy, B.Sc., 8 Highfield Road, Northwood (Middlesex); Henry Arthur Hayward, 7 Little Woodcote Lane, Purley (Surrey); Deryk Livingston Herbage, B.A., B.Sc., 23 Lambolle Road, Hampstead, N.W. 3; Hugh Stamford Raffles Lindeman, Belton Rectory, Great Yarmouth; Michael Henry Mason, Eynsham Hall, Witney (Oxfordshire); James Phemister, M.A., B.Sc., H.M.Geological Survey, 33 George Square, Edinburgh; Cyril James Stubblefield, B.Sc., Demonstrator of Geology in the Imperial College of Science & Technology, South Kensington, S.W. 7; William Munro Tapp, LL.D., F.S.A., Queen Anne's Mansions, St. James's

Park, S.W. 1; Martin Lewis Thomas, B.Sc., Assoc.M.Inst.C.E., 42 Maison Dieu Road, Dover; William George Cheslyn Tomalin, A.R.S.M., B.Sc., Waynfleet, Ross (Herefordshire); Joseph Pierre de Verteuil, c/o the Anglo-Persian Oil Company, Ltd., Britannic House, Great Winchester Street, E.C. 2; and Edwin Williams, B.Sc., The Risca Printing Works, Risca (Monmouthshire), were elected Fellows of the Society.

The following communications were read:—

1. 'On a Hybodont Shark (*Tristychius*) from the Calciferous Sandstone Series of Eskdale (Dumfries-shire).' By Arthur Smith Woodward, LL.D., F.R.S., F.L.S., F.G.S.

2. 'On a Recently Discovered Breccia-Bed underlying Nechells (Birmingham), and its Relations to the Red Rocks of the District.' By Prof. William S. Boulton, D.Sc., F.G.S.

February 6th, 1924.

Prof. A. C. Seward, Sc.D., F.R.S., President, in the Chair

Frank Smithson, B.Sc., 24 Milton Street, Darlington; and David Mowat Watson, B.Sc., 46 Featherstone Road, King's Heath, Birmingham, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'The Upper Towy Drainage-System.' By Prof. Owen Thomas Jones, M.A., D.Sc., F.G.S.

ANNUAL GENERAL MEETING.

February 15th, 1924.

Prof. ALBERT CHARLES SEWARD, Sc.D., F.R.S.,
President, in the Chair.

REPORT OF THE COUNCIL FOR 1923.

DURING the year 43 new Fellows were elected into the Society (41 less than in 1922), and two Fellows were re-instated; of the Fellows elected in 1923, 33 paid their Admission Fees before the end of that year, and, of the Fellows who had been elected in the previous year 16 paid their Admission Fees in 1923, making the total accession of new Fellows during the past year amount to 49 (28 less than in 1922).

Allowing for the loss of 54 Fellows (14 resigned, 30 deceased, and 10 removed), it will be seen that there is a decrease of 3 in the number of Fellows (as compared with an increase of 36 in 1922).

The total number of Fellows is, therefore, at present 1276, made up as follows: —Compounders 188 (7 less than in 1922); Contributing Fellows 1079 (4 more than in 1922); and Non-Contributing Fellows 9 (the same as in 1922).

With regard to the Lists of Foreign Members and Foreign Correspondents, it will be remembered that, at the end of 1922, there were 6 vacancies in the List of Foreign Members and 14 in that of Foreign Correspondents. These have been, for the greater part, filled by the election of 4 Foreign Members and 14 Foreign Correspondents. The Council regrets to have to announce the recent decease of Prof. Fusakichi Omori, Foreign Correspondent. Consequently, there remain 2 vacancies in the List of Foreign Members, and 5 in that of Foreign Correspondents.

The Ordinary Receipts of the year, including the Balance in hand and interest on the Sorby and Hudleston Bequests, amounted to £4248 16*s*. 3*d*., and the Expenditure to £4602 17*s*. 10*d*., showing a deficit of £354 1*s*. 7*d*. The Expenditure included £638 16*s*. 2*d*. for printing the Lists of Geological Literature for 1914 and for 1915–19, and this was in part met by a grant of £100 from the Royal Society. A further sum of £190 8*s*. 8*d*. was defrayed from the Voluntary Publication Fund, to be mentioned later, this being the excess spent on the Quarterly Journal over the £1000 included in the Estimates for the year. The actual deficit on the Accounts was, therefore, £63 12*s*. 11*d*. The Estimates for 1924, after providing for the deficit, show a small balance; but, as the

Council has decided to devote the balance of the proceeds of the Prestwich and Barlow-Jameson Funds to Publications, the sum of £106 1*s*. 9*d*. will be available for that purpose, besides such sums as may be applied to additional expenditure on the Quarterly Journal out of the Voluntary Publication Fund.

The increased expense of producing the Quarterly Journal, consequent on the rise of prices after the War, created a serious situation. The money in hand was insufficient to meet the demand, and arrears accumulated. It was decided in April 1923 to appeal to the Fellows for Contributions to a Voluntary Publication Fund. The amount at present available is £229 17*s*. 10*d*., and a further £170 2*s*. 0*d*. received or promised during 1924.

It is hoped that further Contributions will be received, and that a permanent Voluntary Publication Fund will be maintained. The policy, which commends itself to the Council, in relation to the Fund, may be briefly stated. The Fund should, in future, be treated as a separate Fund, and not included in the Balance-Sheet of the Society. It should be allocated solely to the publication of the Journal, grants being found from it to meet publication expenses in excess of the amount available from ordinary sources; in special cases, it should be utilized for the provision of coloured maps, or in other ways likely to enhance the value and efficiency of the Society's Journal.

Vol. LXXIX of the Quarterly Journal, for 1923, was completed by the publication of the fourth part on December 29th of that year. The volume contained 23 papers, published at a cost of £1190 8*s*. 8*d*. There now remain outstanding thirteen papers (seven belonging to previous Sessions, and six to the present Session). The probable total cost of publication of these alone will amount to about £950. The notable increase in the number of papers published was made possible by the generous support given by the Fellows to the Voluntary Publication Fund.

The Publication Committee has drawn up a series of 'Instructions to Authors of Papers intended for Publication in the Society's Journal', which have been approved by the Council, and copies will be issued, on application, to prospective authors.

This Society's Apartments have been used for General Meetings, and for Council or Committee Meetings during the past year by the Institution of Mining Engineers, the Institution of Mining & Metallurgy, the Institution of Water Engineers, the Society of Engineers, the Mineralogical Society, the Palæontographical Society, the Persia Society, the Ray Society, the Geologists' Association, and the South-Eastern Union of Scientific Societies.

Mr. W. Whitaker was nominated as Delegate to the Hull Congress of the Royal Sanitary Institute; Mr. W. Campbell Smith as Delegate to the Conference of Corresponding Societies at the British Association Meeting in Liverpool; Prof. Sir T. W. Edgeworth David as Delegate at the Meeting of the Pan-Pacific Science Congress held in Australia in August last; Mr. R. R. Lemprière as Delegate at the Jubilee Celebration of the Société Jersiaise; and

Prof. W. B. Scott as Delegate at the Joseph Leidy Commemorative Meeting arranged by the Academy of Natural Sciences of Philadelphia.

The Council has had in view the fact that the many new roads now being planned may expose sections of great geological interest, and has asked the Ministry of Transport and all County Surveyors to arrange to report when such sections are exposed, so that local geologists may be informed. The Ministry of Transport has offered to supply the information for the arterial roads of Greater London, and the Geologists' Association has volunteered to arrange for these roads to be watched. The Council hopes that Fellows throughout the country will assist this scheme as much as possible, by keeping a watch on any important cuttings in their districts.

Two chairs, formerly the property of William Smith, were presented by Mr. R. W. Williamson, on his behalf and on that of the other children of the late Prof. W. Crawford Williamson.

A geological hammer, chisel, and map-case, formerly belonging to George Bellas Greenough, first President and one of the Founders of the Society, together with a series of letters and papers referring to the Society, were presented by Miss P. de B. F. Bowen-Coulthurst.

A change in the composition of the Permanent Staff has taken place, in consequence of the resignation of the Clerk, Mr. M. St. John Hope, in April last. The supervision of the Clerk's duties has been taken over by the Librarian, and Miss G. V. Bridgman has been appointed to assist him.

A grant of £25 has been sanctioned by the Council, from the Gloyne Outdoor Geological Research Fund, for the purpose of carrying out an investigation of the bone-caves of the Gower Peninsula, and Prof. W. J. Sollas has been nominated as supervisor of the work on behalf of the Council.

The proceeds of the Daniel-Pidgeon Fund for 1923 have been awarded to Mr. Howel Williams, of Liverpool University, who proposes to carry out researches on the Stratigraphy and Vulcanicity of Snowdon.

Further, the following Awards of Medals and Funds have been made:—

The Wollaston Medal is awarded to Dr. Arthur Smith Woodward, in recognition of his researches 'concerning the mineral structure of the Earth', especially in connexion with the Palæontology of the Vertebrata.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Dr. Walcot Gibson, as an acknowledgment of the value of his researches on the younger Palæozoic rocks of Great Britain, more especially of the Coal Measures of the Midland and South Wales coalfields.

The Lyell Medal, together with a sum of Twenty-five Pounds from the Lyell Geological Fund, is awarded to Mr. William Wickham King, in recognition of his researches on the Palæozoic rocks of Britain, more particularly those connected with the

Devonian and Silurian, and on the Breccias in the Red Rocks of the Midlands.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Dr. Cecil Edgar Tilley, in recognition of the value of his researches in Petrology, both in Great Britain and in South Australia.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Dr. Leonard Frank Spath, in recognition of the value of his researches on the Ammonoidea.

A Moiety of the Balance of the Lyell Geological Fund is awarded to Mr. John William Tutcher, in recognition of the value of his researches on the Jurassic rocks of the Bristol area, and of the contribution to the illustration of Palæontological Literature which his photographic skill has enabled him to make.

A second Moiety of the Balance of the Lyell Geological Fund is awarded to Mr. Hugh Hamshaw Thomas, in recognition of the value of his researches in Palæobotany.

The proceeds of the Prestwich and Barlow-Jameson Funds have been allocated by the Council to meet part of the Expenditure on the Society's publications.

Report of the Library Committee for 1923.

During the year 1923 the Accessions to the Library equalled, both in number and importance, those of the preceding years. They approach, indeed, the additions registered in the years before the War.

The Donations received during the year number 52 volumes of separately published works, 811 pamphlets, and 6 detached parts of works; also 131 complete volumes and 385 parts of serial publications; 262 volumes and 328 parts of the publications of Geological Surveys and other public bodies, and 12 volumes of weekly periodicals. The number of accessions by donation amounts, therefore, to 457 volumes, 719 detached parts, and 811 pamphlets. The Donors during 1923 included 126 Government Departments and other public bodies, 145 Societies and Editors of periodicals, and 110 individual Donors.

Two acquisitions, in particular, are worthy of especial mention. A number of original geological and other drawings by Dr. John MacCulloch, President of the Society from 1816 to 1818, together with several books from his library, were presented by Miss Emily Estridge. A collection of pamphlets, principally dealing with the Geology of the East of England, from the library of the late Mr. F. W. Harmer, was presented by Sir Sidney F. Harmer.

A number of new serials were received in exchange for the

publications of this Society, and among them the following may be mentioned:—

'Pan-American Geologist' (successor to 'The American Geologist'); Geological Survey of China—Bulletin, Memoirs, Palæontologia Sinica, and Special Reports; Bulletin of the Geological Society of China; and the Imperial Institute Monographs on Mineral Resources, with special reference to the British Empire.

Further, 101 sheets of geological maps were received, including 38 sheets from the Geological Survey of Scotland, and 10 and 5 respectively from the Geological Surveys of England and Ireland.

The more important of these Donations, both of the books and the maps, have already been enumerated in the Abstracts of Proceedings.

The purchases during 1923 include 30 volumes and 33 detached parts of works published separately, 52 volumes and 36 parts of serials, and 4 sheets of maps. Attention may be drawn to the following:—

'The Evolution of Climate', by C. E. P. Brooks; 'Cements & Artificial Stone', by J. Watson; 'Climatic Changes', by E. Huntington & S. S. Visher; 'Grundzüge einer Physioklimatologie der Festländer', by W. R. Eckardt; 'Die Fossilisation', by W. Deecke; 'Geologie von Mexiko', by W. Freudenberg; 'Handbuch der Palæogeographie', by T. Arldt; 'Beiträge zur Geologie Westturkestans', by R. von Klebelsberg; 'The Ore-Magmas', by J. E. Spurr; 'Das Batholithenproblem', by H. Cloos; 'The Fundamental Principles of Petrology', by E. Weinschenk (translated by A. Johannsen); and 'Handbuch der Regionalen Geologie—Greenland, Asia Minor, Egypt, North-Atlantic Polar Islands, & Caucasus'.

During the year 206 volumes were bound. This figure shows a considerable increase over those of recent years; but binding costs are still high, and much urgent work under this head is necessarily postponed.

The number of books borrowed from the Library was 1199, of which 713 were borrowed personally, and 486 were sent through the post.

During the year under review the List of Geological Literature for 1915–1919 was published with Author- and Subject-Indexes, and the List for 1922 with Author-Index only. The manuscript of the List for 1923 was compiled during that year, and is now being prepared for press. The incorporation in the Card-Catalogue of the Author-Lists for 1914 and 1922 has been completed, and the incorporation of the Author-List for 1915–1919 is proceeding. When this is finished the Author-Catalogue will be complete to 1922. The Subject-and-Locality Catalogue is now complete to the end of 1913.

The Expenditure incurred in connexion with the Library during the year 1923 was as follows:—

	£	s.	d.
For Books and Periodicals	74	7	0
For Binding and Map-Mounting	85	12	5
For Sundries	1	10	7
Total	£161	10	0

The appended Lists contain the Names of Government Departments and other Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review :—

I. Government Departments and other Public Bodies.

Alabama.—Geological Survey. Montgomery (Ala.).
American Museum of Natural History. New York.
Australia, Government of the Commonwealth of.
Australia (South), etc. *See* South Australia, *etc.*
Baden.—Geologische Landesanstalt. Heidelberg.
Barcelona.—Museu de Ciències Naturals.
Bavaria.—Oberbergamt & Geologische Landesuntersuchung. Munich.
Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique. Brussels.
Belgrade.—Institut Géologique de l'Université.
Bergens Museum. Bergen.
Berlin.—Preussische Akademie der Wissenschaften.
Bristol Museum & Art Gallery.
British Columbia.—Ministry of Mines. Victoria (B.C.).
Brussels.—Musée Royal d'Histoire Naturelle de Belgique.
California.—Academy ot Sciences. San Francisco.
——, University of. Berkeley (Cal.).
Cambridge (Mass.).—American Academy of Arts & Sciences.
——. Museum of Comparative Zoology in Harvard College.
Canada.—Geological Survey. Ottawa.
——. Department of Mines. Ottawa.
Cape Town.—South African Museum.
Cardiff.—National Museum of Wales.
Chicago.—Field Museum of Natural History.
Chicago Academy Natural History Survey.
China.—Geological Survey. Peking.
Connecticut.—State Geological & Natural History Survey. Hartford (Conn.).
Córdoba (Argentine Republic).—Academía Nacional de Ciencias.
Czecho-Slovakia.—Státního Geologického Ústavu. Prague.
Denmark.—Geologiske Undersögelse. Copenhagen.
——. Kommission for Ledelsen af de Geologiske & Geografiske Undersögelser i Grönland. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Ministry of Finance (Survey Department). Cairo.
Federated Malay States.—Government Geologist. Kuala Lumpur.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Ministère de l'Instruction Publique. Paris.
——. Muséum d'Histoire Naturelle. Paris.
——. Service Hydrographique de la Marine. Paris.
French Indo-China.—Service Géologique. Hanoi-Haiphong.
Gold Coast.—Geological Survey. Accra.
Great Britain.—Colonial Office. London.
——. Geological Survey. London.
——. Imperial Institute. London.
——. Imperial Mineral Resources Bureau. London.
——. Mines Department. London.
Hesse.—Geologische Landesanstalt. Darmstadt.
Holland.—Departement van Kolonien. The Hague.
Honolulu.—Hawaiian Volcano Observatory.
Illinois.—Geological Survey. Urbana (Ill.).
India.—Geological Survey. Calcutta.
——. Trigonometrical Survey. Dehra Dun.
Ireland.—Geological Survey. Dublin.
Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
——. National Research Council. Tokio.
Jena.—Geological Department of the University.
Kansas University. Lawrence (Kan.).

Kentucky.—Geological Survey. Frankfort (Ky.).
La Plata.—Museo de La Plata.
Lausanne.—University of.
London.—British Museum (Natural History).
——. Metropolitan Water Board.
Madrid.—Museo de Ciencias Naturales.
——. Real Academía de Ciencias Exactas, Físicas & Naturales.
Mexico.—Instituto Geológico. Mexico City.
——. Secretaria de Industria, Comercio & Trabajo. Mexico City.
Milan.—Reale Istituto Lombardo di Scienze & Lettere.
Minnesota.—Geological Survey. Minneapolis.
——. School of Mines. Minneapolis.
Missouri University, School of Mines & Metallurgy. Rolla (Mo.).
Moscow.—'Lithogæa' Institute.
Munich.—Bayerische Akademie der Wissenschaften.
Mysore.—Geological Department. Bangalore.
New South Wales.—Department of Mines. Sydney.
——. Geological Survey. Sydney.
New York State Museum. Albany (N.Y.).
New Zealand.—Board of Science & Art. Wellington.
——. Department of Lands & Surveys. Wellington.
——. Department of Mines. Wellington.
——. Dominion Museum. Wellington.
——. Geological Survey. Wellington.
Nigeria.—Geological Survey.
Norway.—Geologiske Undersökelse. Christiania.
Norwich Castle Museum Committee.
Ontario.—Department of Mines. Toronto.
Padua.—Istituto Geologico della R. Università.
Paris.—Académie des Sciences.
Peru.—Ministerio de Fomento. Lima.
Philippine Is.—Department of the Interior: Bureau of Science. Manila.
Pinheiro.—Escola Superior da Agricultura & Medecina Veterinaria.
Poland.—Service Géologique. Warsaw.
Portici.—Reale Scuola di Agricoltura.
Prussia.—Preussische Geologische Landesanstalt. Berlin.
Quebec.—Department of Colonization, Mines, & Fisheries.
Queensland.—Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Rhodesian Museum. Bulawayo.
Rome.—Comitato Glaciologico Italiano.
——. Reale Accademia dei Lincei.
Rumania.—Academia Românǎ. Bucarest.
Scotland.—Geological Survey. Edinburgh.
Sendai.—Tôhoku Imperial University.
South Africa.—Department of Mines. Pretoria.
——. Geological Survey. Pretoria.
South Australia. Department of Mines. Adelaide.
——. Geological Survey. Adelaide.
Southern Rhodesia.—Geological Survey. Salisbury.
Spain.—Instituto Geologico. Madrid.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Switzerland.—Geologische Kommission der Schweiz. Berne.
Tasmania.—Secretary for Mines. Hobart.
Tokio.—College of Science.
Travancore.—Department of Geology. Trivandrum.
Uganda.—Geological Survey. Entebbe.
United States.—Department of Commerce, Coast & Geodetic Survey. Washington (D.C.).
——. Geological Survey. Washington (D.C.).
——. National Academy of Sciences & National Research Council. Washington (D.C.).
—— National Museum. Washington (D.C.).
Victoria (Australia). Geological Survey. Melbourne.
——. State Rivers & Water Commission. Melbourne.
Vienna.—Akademie der Wissenschaften.
——. Naturhistorisches Museum.

Washington University. St. Louis (Mo.).
Washington (D.C.).—Carnegie Institution.
——. Geophysical Laboratory.
——. Smithsonian Institution.
Western Australia.—Department of Mines. Perth.
——. Geological Survey. Perth.

II. Societies and Editors.

Adelaide.—Royal Society of South Australia.
Belfast.—Natural History Society.
Bergen.—'Naturen.'
Berlin.—Deutsche Geologische Gesellschaft.
——. Palæontologische Gesellschaft.
——. Zeitschrift für Berg-, Hütten-, & Salinenwesen.
Berne.—Naturforschende Gesellschaft.
Bombay Branch of the Royal Asiatic Society.
Bordeaux.—Société Linnéenne.
Boston (Mass.).—American Academy of Arts & Sciences.
Bristol Naturalists' Society.
Brunswick.—Verein für Naturwissenschaft zu Braunschweig.
Brussels.—Société Belge de Géologie.
——. Société Royale Zoologique & Malacologique de Belgique.
Buenos Aires.—Sociedad Cientifica Argentina.
Caen.—Société Linnéenne de Normandie.
Calcutta.—Asiatic Society of Bengal.
——. Institute of Engineers (India).
Cambridge Philosophical Society.
Cape Town.—Royal Society of South Africa.
——. South African Association for the Advancement of Science.
Cardiff.—South Wales Institute of Engineers.
Chambéry.—Société d'Histoire Naturelle de Savoie.
Chicago.—'Journal of Geology.'
Christiania.—Norsk Geologisk Forening.
Copenhagen.—Académie Royale des Sciences de Danemark.
——. Dansk Geologisk Forening.
Cracow.—Société Géologique de Pologne.
Darmstadt.—Verein für Erdkunde.
Denver.—Colorado Scientific Society.
Des Moines.—'The Pan-American Geologist.'
Dijon.—Académie des Sciences.
Dorchester.—Dorset Natural History & Antiquarian Field-Club.
Dorpat.—Naturforschende Gesellschaft.
Dublin.—Royal Dublin Society.
Edinburgh.—Geological Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg i. B.—Naturforschende Gesellschaft.
Geneva.—Société de Physique & d'Histoire Naturelle.
Glasgow.—Geological Society.
Gloucester.—Cotteswold Naturalists' Field-Club.
Hague, the.—Société Hollandaise des Sciences.
Halifax (Nova Scotia).—Nova Scotian Institute of Science.
Halle a. d. Saale.—Zeitschrift für Praktische Geologie.
Hamilton Association. Hamilton (Ont.).
Hereford.—Woolhope Naturalists' Field-Club.
Hertford.—Hertfordshire Natural History Society.
Johannesburg.—Geological Society of South Africa.
Lausanne.—Société Vaudoise des Sciences Naturelles.
Leeds Geological Association.
Leeds.—Yorkshire Geological Society.
Leicester Literary & Philosophical Society.
Leipzig.—Zeitschrift für Krystallographie.

Liége.—Société Géologique de Belgique.
Lille.—Société Géologique du Nord.
Lima.—Asociación Peruana para el Progreso de la Ciencia.
Lisbon.—Academia das Sciencias.
Liverpool Geological Society.
London.—British Association for the Advancement of Science.
——. Chemical Society.
——. 'The Chemical News.'
——. 'The Colliery Guardian.'
——. 'Fuel.'
——. 'The Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Institution of Mining Engineers.
——. Institution of Mining & Metallurgy.
——. Institution of Water Engineers.
——. Iron & Steel Institute.
——. Linnean Society.
——. 'The London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'The Mining Journal.'
——. 'The Mining Magazine.'
——. 'Nature.'
——. 'The Naturalist.'
——. 'Oil-Engineering & Finance.'
——. 'The Petroleum World.'
—— 'The Quarry.'
——. 'Roads & Road Construction.'
——. Royal Agricultural Society.
——. Royal Astronomical Society.
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society.
——. Royal Society.
——. Royal Society of Arts.
——. Society of Engineers.
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Madison.—Wisconsin Academy of Science.
Manchester.—Literary & Philosophical Society.
Marlborough.—Marlborough College Natural History Society.
Melbourne (Victoria).—Australasian Institute of Mining & Metallurgy.
——. Royal Society of Victoria.
——. 'The Victorian Naturalist.'
Mexico.—Sociedad Científica 'Antonio Alzate.'
Milan.—Società Italiana di Scienze Naturali.
Naples.—Accademia delle Scienze Fisiche & Matematiche.
Newcastle-upon-Tyne.—North of England Institute of Mining & Mechanical Engineers.
——. University of Durham Philosophical Society.
New Haven (Conn.).—Academy of Arts & Sciences.
——. 'The American Journal of Science.'
New York.—American Institute of Mining & Metallurgical Engineers.
Northampton.—Northamptonshire Natural History Society.
Ottawa.—Royal Society of Canada.
Palermo.—'Il Naturalista Siciliano.'
Paris.—Annales des Mines.
——. Société Géologique de France.
Peking.—Geological Society of China.
Perth.—Perthshire Society of Natural Sciences.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.

Rennes.—Société Géologique & Minéralogique de Bretagne.
——. Société Scientifique et Médicale de l'Ouest.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Santiago de Chile.—Sociedad Nacional de Minería.
Stockholm.—Geologiska Förening.
Stratford.—Essex Field-Club.
Stuttgart.—Centralblatt für Mineralogie, &c.
——. Verein für Naturkunde Württembergs.
Sydney (N.S.W.).—Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Torquay Natural History Society.
Toulouse.—Société d'Histoire Naturelle.
Turin.—Reale Accademia delle Scienze.
Upsala.—Geological Institution of the University.
Valparaiso.—Deutscher Wissenschaftlicher Verein zu Santiago.
Vienna.—Geologische Gesellschaft.
——. Berg- & Hüttenmännisches Jahrbuch.
——. Zoologisch-Botanische Gesellschaft.
Washington (D.C.).—Geological Society of America.
Whitby Literary & Philosophical Society.
Worcester.—Naturalists' Club.
York.—Yorkshire Philosophical Society.
Zürich.—Schweizerische Naturforschende Gesellschaft.

III. Personal Donors.

Ami, H. M.

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Boswell, P. G. H.
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Freygang, J.

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Gregory, J. W.
Guébhard, A.

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Harmer, Sir Sidney.
Hatch, F. H.
Haughton, S. H.
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Högbom, I.
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Hunter, C. M.

Jillson, W. R.

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Newton, R. B.
Nopcsa, Baron F.

Oldham, R. D.
Osborn, H. F.

Parks, W. A.
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Penck, A.
Plymen, G. H.
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Van Baren, J.
Van Straelen, V.
Van Wingen, N.

Warren, S. H.
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Williams, H.
Wilson, G. V.
Withers, T. H.
Woolacott, D.

List of Donors to the Voluntary Publication Fund.

Adams, F. D.
Ami, H. M.
Anderson, E. M.
Andrew, A. R.
Ashcroft, F. N.

Baden-Powell, D. F. W.
Bailey, E. B.
Barrow, G.
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Garwood, E. J.
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Grabham, G. W.
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Greenly, E.
Gregory, J. W.

Harker, A.
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Hayden, Sir Henry H.
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Horne, J.
Hume, W. F.

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Lake, P.
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Strahan, Sir Aubrey.
Stuart, D. M. D.

Teall, Sir Jethro.
Tunbridge, E. W.
Turner, H. W.

Watt, W. R.
Watts, W. W.
Whitaker, W.
Wills, L. J.

Comparative Statement of the Number of the Society at the Close of the Years 1922 and 1923.

	Dec. 31st, 1922.		Dec. 31st, 1923.
Compounders	195	....	188
Contributing Fellows	1075	....	1079
Non-Contributing Fellows	9	....	9
	1279		1276
Foreign Members	34	....	38
Foreign Correspondents	26	....	36
	1339		1350

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the Years 1922 and 1923.

Number of Compounders, Contributing, and Non-Contributing Fellows, December 31st, 1922		1279
Add Fellows elected during the former year and paid in 1923		16
Add Fellows elected and paid in 1923		33
Add Fellows re-instated		2
		1330
Deduct Compounders deceased	8	
Contributing Fellows deceased	22	
Contributing Fellows resigned	14	
Fellows removed in accordance with Sect. VI, Art. 5, of the Bye-Laws	10	
	—	54
		1276
Number of Foreign Members and Foreign Correspondents, December 31st, 1922	60	
Add 14 Foreign Correspondents elected	14	
	—	74
		1350

Deceased Fellows.

Compounders (8).

Collingwood, J. F. [elected in 1861].
Hall, H. F. [el. 1865].
Harmer, F. W. [el. 1869].
Hills, R. C. [el. 1884].
Holmes, T. V. [el. 1876].
Ridsdale, Sir Edward A. [el. 1889].
Smith, R. C. [el. 1873].
Wright, J. [el. 1866].

Contributing Fellows (22).

Ballot, J. [elected in 1898].
Blackmore, J. C. [el. 1888].
Carey, A. E. [el. 1887].
Curtis, A. H. [el. 1891].
Gresley, W. S. [el. 1877].
Hayden, Sir Henry H. [el. 1900].
Herries, Sir William [el. 1885].
Hooley, R. W. [el. 1904].
Howorth, Sir Henry H. [el. 1891].
Johnston, J. [el. 1898].
Lawder, A. W. [el. 1872].
Le Lacheur, W. J. [el. 1890].
Lindsay, the Rev. J. [el. 1888].
Lisboa, M. A. [el. 1909].
Molineux, H. P. [el. 1888].
Palmer, R. W. [el. 1918].
Reader, T. W. [el. 1891].
Stewart, P. C. A. [el. 1904].
Thomas, A. E. [el. 1917].
Vredenburg, E. W. [el. 1907].
Whealler, J. E. A. [el. 1923].
Williams, G. D. [el. 1913].

Fellows Resigned (14).

Broad, P. G.
Broom, G. J. C.
Brown, G. E.
Brown, G. L.
Brown, W. A.
Churchward, A.
Finnemore, J.
Jeffery, J. L.
McNeill, H. C.
Robertson, E. H.
Robertson, T.
Russell, A.
Schon, B.
Wilson, L. E.

Fellows Removed (10).

Collins, P. H.
Hutchison, L. G.
MacAlister, W. W.
Page, H. M.
Smith, R. H.
Spencer, J.
Thomas, T. S.
Wasse, F. M.
Weaver, H. J.
Yone, N.

Fellows Elected (43)

Baden-Powell, D. F. W.
Banerji, A. K.
Banks, H. F.
Barnard, R.
Bowman, T. S.
Burton, E. W. St. J.
Canning, W. F.
Clayton, R.
Clutterbuck, E. C.
Combe, A. D.
Cook, Miss A. E.
Cooper, the Rev. C. W.
Dunn, J. A.
Farquharson, D. J.
Fleet, W. F.
Fox, J. R.

Fellows Elected (*cont.*).

Gaster, C. T. A.
Grange, L. I.
Guest, A. W.
Hardcastle, A.
Higham, F.
Hitchon, T.
Holmes, S.
Jackson, J. F.
John, D. J.
Keep, C. E.
Kirkby, W. H.
Lees, G. M.
Lewis, G. G.
Morton, E.
Murray-Hughes, R.
Perl, A.
Southwell, C. A. P.
Stevens, P. G.
Talbot, G. K.
Thomas, E. G.
Vincent, H. G. C.
Vivian, J. C.
Vobe, Miss M.
Whealler, J. E. A.
White, E. I.
Wilkins, L. G.
Willbourne, E. S.

After the Reports had been read, it was resolved :—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved :—

That the thanks of the Society be given to Prof. A. C. Seward, retiring from the office of President; to Dr. J. W. Evans, retiring from the office of Vice-President; to Mr. R. D. Oldham and Dr. Herbert H. Thomas, retiring from the office of Vice-President, and also from the Council; and to the other retiring Members of Council: Prof. W. S. Boulton, Prof. O. T. Jones, Mr. W. B. R. King, and Sir Jethro Teall.

After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year :—

OFFICERS AND COUNCIL.—1924.

PRESIDENT.

John William Evans, C.B.E., D.Sc., LL.B., F.R.S.

VICE-PRESIDENTS.

Charles William Andrews, B.A., D.Sc., F.R.S.
John Smith Flett, O.B.E., M.A., LL.D., D.Sc., M.B., F.R.S.
Prof. Albert Charles Seward, Sc.D., F.R.S., F.L.S.
Prof. William Whitehead Watts, LL.D., Sc.D., M.Sc., F.R.S.

SECRETARIES.

Walter Campbell Smith, M.C., M.A.
James Archibald Douglas, M.A., D.Sc.

FOREIGN SECRETARY.

Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.

TREASURER.

Robert Stansfield Herries, M.A.

COUNCIL.

Charles William Andrews, B.A., D.Sc., F.R.S.
Frederick Noel Ashcroft, M.A., F.C.S.
Prof. Percy George Hamnall Boswell, O.B.E., D.Sc.
Prof. Arthur Hubert Cox, D.Sc., Ph.D.
Henry Dewey.
James Archibald Douglas, M.A., D.Sc.
Gertrude Lilian Elles, M.B.E., D.Sc.
John William Evans, C.B.E., D.Sc., LL.B., F.R.S.
John Smith Flett, O.B.E., M.A., LL.D., D.Sc., M.B., F.R.S.
Sir Archibald Geikie, O.M., K.C.B., D.C.L., LL.D., Sc.D., F.R.S.
Frederick Henry Hatch, O.B.E., Ph.D.
Prof. Herbert Leader Hawkins, D.Sc.
Robert Stansfield Herries, M.A.
Sir Thomas Henry Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S.
William Dickson Lang, M.A., Sc.D.
Tressilian Charles Nicholas, O.B.E., M.A.
Prof. Sidney Hugh Reynolds, M.A., Sc.D.
Prof. Albert Charles Seward, Sc.D., F.R.S., F.L.S.
Walter Campbell Smith, M.C., M.A.
Leonard James Spencer, M.A., Sc.D.
Sir Aubrey Strahan, K.B.E., Sc.D., LL.D., F.R.S.
Prof. William Whitehead Watts, LL.D., Sc.D., M.Sc., F.R.S.
Henry Woods, M.A., F.R.S.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1923.

Date of Election.

1886. Prof. Gustav Tschermak, *Vienna.*
1891. Prof. Charles Barrois, *Lille.*
1893. Prof. Waldemar Christofer Brögger, *Christiania.*
1894. Prof. Edward Salisbury Dana, *New Haven, Conn.* (*U.S.A.*).
1896. Prof. Albert Heim, *Zürich.*
1898. Dr. Charles Doolittle Walcott, *Washington, D.C.* (*U.S.A.*).
1899. Prof. Emanuel Kayser, *Munich.*
1899. M. Ernest Van den Broeck, *Brussels.*
1900. M. Gustave F. Dollfus, *Paris.*
1900. Prof. Paul von Groth, *Munich.*
1901. Dr. Alexander Petrovich Karpinsky, *Petrograd.*
1901. Prof. Antoine François Alfred Lacroix, *Paris.*
1903. Prof. Albrecht Penck, *Berlin.*
1903. Prof. Anton Koch, *Budapest.*
1904. Prof. Henry Fairfield Osborn, *New York* (*U.S.A.*).
1905. Prof. Louis Dollo, *Brussels.*
1907. Dr. Emil Ernst August Tietze, *Vienna.*
1908. Prof. Bundjirô Kôtô, *Tokyo.*
1909. Prof. Johan H. L. Vogt, *Trondhjem.*
1911. Prof. Baron Gerard Jakob De Geer, *Stockholm.*
1911. M. Emmanuel de Margerie, *Strasbourg.*
1912. Prof. Marcellin Boule, *Paris.*
1913. Prof. Johannes Walther, *Halle an der Saale.*
1914. Prof. Friedrich Johann Becke, *Vienna.*
1914. Prof. Thomas Chrowder Chamberlin, *Chicago, Ill.* (*U.S.A.*).
1914. Prof. Franz Julius Lœwinson-Lessing, *Petrograd.*
1914. Prof. Alexis Petrovich Pavlow, *Moscow.*
1914. Prof. William Berryman Scott, *Princeton, N.J.* (*U.S.A.*).
1921. Dr. Frank Wigglesworth Clarke, *Washington, D.C.* (*U.S.A.*).
1921. Prof. Émile Haug, *Paris.*
1921. Prof. Maurice Lugeon, *Lausanne.*
1921. Prof. Hans Schardt, *Zürich.*
1921. Dr. Jakob Johannes Sederholm, *Helsingfors.*
1921. Dr. Henry Stephens Washington, *Washington, D.C.* (*U.S.A.*).
1923. Prof. Lucien Cayeux, *Paris.*
1923. Prof. John M. Clarke, *Albany, N.Y.* (*U.S.A.*).
1923. Prof. Henri Douvillé, *Paris.*
1923. Prof. Waldemar Lindgren, *Boston, Mass.* (*U.S.A.*).

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1923.

Date of Election.

1889. Dr. Rogier Diederik Marius Verbeek, *The Hague.*
1898. Dr. W. H. Dall, *Washington, D.C.* (*U.S.A.*).
1899. Dr. Gerhard Holm, *Stockholm.*
1900. Prof. Federico Sacco, *Turin.*
1902. Dr. Thorvaldr Thoroddsen, *Copenhagen.*
1904. Dr. Erich Dagobert von Drygalski, *Charlottenburg.*
1904. Prof. Giuseppe de Lorenzo, *Naples.*
1904. The Hon. Frank Springer, *East Las Vegas, New Mexico* (*U.S.A.*).
1906. Prof. William Morris Davis, *Cambridge, Mass.* (*U.S.A.*).
1909. Dr. Daniel de Cortázar, *Madrid.*
1911. Prof. Arvid Gustaf Högbom, *Upsala.*
1911. Prof. Charles Depéret, *Lyons.*
1912. Dr. Whitman Cross, *Washington, D.C.* (*U.S.A.*).
1912. Baron Ferencz Nopcsa, *Vienna.*
1912. Prof. Karl Diener, *Vienna.*
1912. Prof. Fusakichi Omori, *Tokyo.* (*Deceased.*)
1913. Dr. Per Johan Holmquist, *Stockholm.*
1921. Dr. Maurice Cossmann, *Paris.*
1921. Prof. Henry de Dorlodot, *Louvain.*
1921. Prof. Louis Duparc, *Geneva.*
1921. Prof. Johan Kiær, *Christiania.*
1921. Prof. John J. Stevenson, *New York City* (*U.S.A.*).
1923. Prof. Emile Argand, *Neuchâtel.*
1923. Prof. Léon William Collet, *Geneva.*
1923. Prof. Reginald Aldworth Daly, *Cambridge, Mass.* (*U.S.A.*).
1923. Prof. G. Delépine, *Lille.*
1923. Prof. Paul Fourmarier, *Liége.*
1923. Prof. Victor Moritz Goldschmidt, *Christiania.*
1923. Prof. Thore Gustafsson Halle, *Stockholm.*
1923. Prof. James Furman Kemp, *New York City* (*U.S.A.*).
1923. Prof. Carl Frederik Kolderup, *Bergen.*
1923. Prof. Carlos I. Lisson, *Lima.*
1923. Prof. Gustaaf Adolf Frederik Molengraaff, *Delft.*
1923. Dr. Armand Rénier, *Brussels.*
1923. Prof. Pierre Termier, *Paris.*
1923. Dr. Frederick Eugene Wright, *Washington, D.C.* (*U.S.A.*).

[NOTE.—The Lists of Awards of Medals and Funds, up to the year 1907 inclusive, are published in the 'History of the Geological Society.']

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND,'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

'To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1908. Prof. Paul von Groth.
1909. Mr. Horace B. Woodward.
1910. Prof. William B. Scott.
1911. Prof. Waldemar C. Brögger.
1912. Sir Lazarus Fletcher.
1913. The Rev. Osmond Fisher.
1914. Prof. John Edward Marr.
1915. Sir T. W. Edgeworth David.
1916. Dr. A. P. Karpinsky.
1917. Prof. A. F. A. Lacroix.
1918. Dr. Charles D. Walcott.
1919. Sir Aubrey Strahan.
1920. Prof. G. J. De Geer.
1921. { Dr. B. N. Peach.
Dr. John Horne.
1922. Dr. Alfred Harker.
1923. Mr. William Whitaker.
1924. Dr. A. Smith Woodward.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1908. Dr. Herbert Henry Thomas.
1909. Mr. Arthur J. C. Molyneux.
1910. Mr. Edward B. Bailey.
1911. Prof. Owen Thomas Jones.
1912. Mr. Charles Irving Gardiner.
1913. Mr. William Wickham King.
1914. Mr. R. Bullen Newton.
1915. Mr. Charles Bertie Wedd.
1916. Mr. William Bourke Wright.
1917. Prof. Percy G. H. Boswell.
1918. Mr. Albert Ernest Kitson.
1919. Dr. A. L. Du Toit.
1920. Mr. William B. R. King.
1921. Dr. Thomas O. Bosworth.
1922. Dr. Leonard J. Wills.
1923. Mr. Harold Herbert Read.
1924. Dr. Cecil Edgar Tilley.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S

'To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1908. Prof. Albert Charles Seward.
1909. Prof. Grenville A. J. Cole.
1910. Prof. Arthur P. Coleman.
1911. Mr. Richard Hill Tiddeman.
1912. Prof. Louis Dollo.
1913. Mr. George Barrow.
1914. Mr. William A. E. Ussher.
1915. Prof. William W. Watts.
1916. Dr. Robert Kidston.
1917. Dr. George F. Matthew.
1918. Mr. Joseph Burr Tyrrell.
1919. Miss Gertrude L. Elles.
1920. Dame E. M. R. Shakespear.
1921. Mr. Edgar Sterling Cobbold.
1922. Dr. John William Evans.
1923. Prof. John Joly.
1924. Dr. Walcot Gibson.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE

'MURCHISON GEOLOGICAL FUND.'

1908. Miss Ethel Gertrude Skeat.
1909. Dr. James Vincent Elsden.
1910. Mr. John Walker Stather.
1911. Mr. Edgar Sterling Cobbold.
1912. Dr. Arthur Morley Davies.
1913. Mr. Ernest E. L. Dixon.
1914. Mr. Frederick Nairn Haward.
1915. Mr. David Cledlyn Evans.
1916. Mr. George Walter Tyrrell.
1917. Dr. William Mackie.
1918. Mr. Thomas Crook.
1919. Mrs. Eleanor Mary Reid.
1920. Dr. David Woolacott.
1921. Dr. Albert Gilligan.
1922. Dr. Herbert Bolton.
1923. Mr. Thomas H. Withers.
1924. Dr. Leonard Frank Spath.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, Bart., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1908. Mr. Richard Dixon Oldham.
1909. Prof. Percy Fry Kendall.
1910. Dr. Arthur Vaughan.
1911. { Dr. Francis Arthur Bather. / Dr. Arthur Walton Rowe. }
1912. Mr. Philip Lake.
1913. Mr. Sydney S. Buckman.
1914. Mr. Charles S. Middlemiss.
1915. Prof. Edmund J. Garwood.
1916. Dr. Charles W. Andrews.
1917. Dr. Wheelton Hind.
1918. Mr. Henry Woods.
1919. Dr. William Fraser Hume.
1920. Dr. Edward Greenly.
1921. M. E. de Margerie.
1922. Dr. Charles Davison.
1923. M. Gustave F. Dollfus.
1924. Mr. W. Wickham King.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1908. Prof. T. Franklin Sibly.
1908. Mr. H. J. Osborne White.
1909. Mr. H. Brantwood Maufe.
1909. Mr. Robert G. Carruthers.
1910. Dr. F. R. Cowper Reed.
1910. Dr. Robert Broom.
1911. Prof. Charles Gilbert Cullis.
1912. Dr. Arthur R. Dwerryhouse.
1912. Mr. Robert Heron Rastall.
1913. Mr. Llewellyn Treacher.
1914. The Rev. Walter Howchin.
1914. Mr. John Postlethwaite.
1915. Mr. John Parkinson.
1915. Dr. Lewis Moysey.
1916. Mr. Martin A. C. Hinton.
1916. Mr. Alfred S. Kennard.
1917. Prof. A. Hubert Cox.
1917. Mr. Tressilian C. Nicholas.
1918. Mr. Vincent Charles Illing.
1918. Mr. William Kingdon Spencer.
1919. Mr. John Pringle.
1919. Dr. Stanley Smith.
1920. Dr. John D. Falconer.
1920. Mr. Ernest S. Pinfold.
1921. Prof. H. L. Hawkins.
1921. Mr. C. E. N. Bromehead.
1922. Mr. Arthur Macconochie.
1922. Mr. David Tait.
1923. Prof. W. N. Benson.
1923. Prof. W. T. Gordon.
1924. Mr. John W. Tutcher.
1924. Mr. H. Hamshaw Thomas.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1909. Dr. John Smith Flett.
1911. Prof. Othenio Abel.
1913. Sir Thomas H. Holland.
1915. Sir Henry Hubert Hayden.
1917. Mr. Robert G. Carruthers.
1919. Sir Douglas Mawson.
1921. Dr. Lewis L. Fermor.
1923. Mr. E. B. Bailey.

AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

'To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1909. Lady (John) Evans.
1912. Library extension.
1915. Prof. Émile Cartailhac.
1918. Sir William Boyd Dawkins.
1921. List of Geological Literature.
1924. List of Geological Literature.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1908. 'Grey-Wether' sarsens on Marlborough Downs.
1911. Mr. John Frederick Norman Green.
1913. { Mr. Bernard Smith.
{ Mr. John Brooke Scrivenor.
1915. Mr. Joseph G. Hamling.
1917. Mr. Henry Dewey.
1921. List of Geological Literature.
1924. Publications (including List of Geological Literature).

AWARDS OF THE PROCEEDS OF THE 'DANIEL-PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

'An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1908. Dr. James A. Douglas.
1909. Dr. Alexander M. Finlayson.
1910. Mr. Robert Boyle.
1911. Mr. Tressilian C. Nicholas.
1912. Mr. Otway H. Little.
1913. Mr. Roderick U. Sayce.
1914. Prof. Percy G. H. Boswell.
1915. Mr. E. Talbot Paris.
1916. Prof. John K. Charlesworth.
1917. Dr. Arthur Holmes.
1918. Mr. James A. Butterfield.
1920. Miss M. E. J. Chandler.
1920. Prof. L. Dudley Stamp.
1921. Mr. Ralph W. Segnit.
1921. Dr. Frederick S. Wallis.
1922. Mr. H. Price Lewis.
1923. Mr. Howel Williams.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions	52	10	0			
Admission-Fees, 1924	315	0	0	367	10	0
Arrears of Annual Contributions	200	0	0			
Annual Contributions, 1924	2240	0	0			
Annual Contributions in advance	50	0	0	2490	0	0
Quarterly Journal Subscriptions	270	0	0			
List of Geol. Lit. Subscriptions	30	0	0	300	0	0
Sale of the Quarterly Journal, including Longmans' Account				250	0	0
Sale of other Publications				20	0	0
Miscellaneous Receipts				40	0	0
Interest on Deposit-Account				7	10	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £2540 Southern Railway 5 per cent. Preference Stock	127	0	0			
Dividends on £3545 London, Midland, & Scottish 4 per cent. Preference Stock	141	16	0			
Dividends on £267 6*s.* 7*d.* Natal 3 per cent. Stock.	8	0	4	351	16	4
Income of Sorby and Hudleston Bequests				70	0	0
				£3896	16	4

the Year 1924.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
Repairs and Maintenance Fund				200	0	0
House-Expenditure:						
Taxes and Insurance	25	0	0			
Electric Lighting	50	0	0			
Gas	30	0	0			
Fuel	50	0	0			
Annual Cleaning	20	0	0			
Washing and Sundry Expenses	70	0	0			
Tea at Meetings	25	0	0			
				270	0	0
Salaries and Wages, etc.				1410	0	0
Office-Expenditure:						
Stationery	50	0	0			
Miscellaneous Printing	110	0	0			
Postages and Sundry Expenses	100	0	0			
List of Fellows	65	0	0			
				325	0	0
Library (Books and Binding)	180	0	0			
(Catalogue Cards)	5	0	0			
				185	0	0
Publications:						
Quarterly Journal (Vol. lxxx)	1000	0	0			
Postage on Journal, Addressing, etc.	40	0	0			
Abstracts of Proceedings, including Postage	240	0	0			
List of Geological Literature for 1923	160	0	0			
				1440	0	0
				£3830	0	0

	£	s.	d.
Deficit at January 1st, 1924	£63	12	11
Estimated Balance at December 31st, 1924	3	3	5
	£3896	16	4

ROBERT S. HERRIES, *Treasurer.*

January 30th, 1924.

RECEIPTS.

Ordinary Receipts.

	£	s.	d.	£	s.	d.
To Balance in the hands of the Bankers at January 1st, 1923:						
Current Account	149	9	1			
„ Balance in the hands of the Clerk at January 1st, 1923	18	4	1			
				167	13	2
„ Compositions				52	10	0
„ Admission-Fees:						
Arrears	100	16	0			
Current	207	18	0			
				308	14	0
„ Arrears of Annual Contributions				203	14	0
„ Annual Contributions for 1923	2312	12	6			
„ Annual Contributions in advance	63	15	0			
				2376	7	6
„ Quarterly Journal Subscriptions	266	2	6			
„ List of Geol. Lit. Subscriptions	51	14	6			
				317	17	0
„ Publications:						
Sale of Quarterly Journal:						
„ Vols. i to lxxviii (less Commission £30 7*s.* 6*d.*)	286	7	9			
„ Vol. lxxix (less Commission £6 7*s.* 4*d.*)	36	15	6			
„ Other Publications (less Commission)	30	14	7			
				353	17	10
„ Miscellaneous Receipts				33	2	8
„ Interest on Deposit				7	9	10
„ Dividends, as received:—						
£2500 India 3 per cent. Stock	75	0	0			
£2540 Southern Railway 5 per cent. Preference Stock	96	0	11			
£3545 London, Midland, & Scottish Railway 4 per cent. Preference Stock	106	18	3			
£267 6*s.* 7*d.* Natal 3 per cent. Stock	6	2	4			
				284	1	6
„ Income-Tax recovered				72	11	3
„ Transfer from Sorby & Hudleston Bequests				70	17	6
„ Excess of Expenditure over Ordinary Receipts				354	1	7
				£4602	17	10

Special Receipts.

				£	s.	d.	£	s.	d.
To Grant from the Royal Society for the List of Geological Literature 1915–19				100	0	0			
„ Transfer from the Voluntary Publication Fund for the Quarterly Journal, being Excess of Expenditure over Estimate				190	8	8			
„ Amount overdrawn at the Bank at December 31st, 1923	£74	12	7						
Less Cash in the Clerk's hands at December 31st, 1923	10	19	8						
				63	12	11			
							354	1	7

PAYMENTS.

	£	s.	d.	£	s.	d.
By Maintenance Fund				250	0	0
,, House-Expenditure:						
Taxes		15	0			
Fire- and other Insurance	22	10	1			
Electric Lighting	45	12	10			
Gas	28	17	7			
Fuel	51	11	0			
Furniture and Repairs	1	0	0			
Annual Cleaning	24	18	1			
Washing and Sundry Expenses	60	5	9			
Tea at Meetings	22	3	10			
				257	14	2
,, Salaries and Wages, etc.:						
Permanent Secretary	550	0	0			
Librarian	350	0	0			
Clerk	143	3	4			
Junior Assistant	130	0	0			
House-Porter and Wife	141	11	0			
Housemaid	76	16	0			
Charwoman and Occasional Assistance	28	4	0			
Accountants' Fee	10	10	0			
Porter's Uniform	7	6	0			
				1437	10	4
,, Office-Expenditure:						
Stationery	35	3	1			
Miscellaneous Printing	115	13	5			
Postages and Sundry Expenses	105	7	10			
				256	4	4
,, Library:						
Books and Binding	160	15	6			
				160	15	6
,, Publications (current year):						
Quarterly Journal, Vol. lxxix, Paper, Printing, and Illustrations	1190	8	8			
Postage on Journal, Addressing, etc.	33	13	5			
Abstracts, including Postage	216	2	0			
List of Geological Literature for 1922	161	13	3			
				1601	17	4
,, Publications (arrears of):—						
List of Geological Literature for 1914	156	6	7			
,, ,, ,, for 1915–19.	482	9	7			
				638	16	2
				£4602	17	10

By Excess of Expenditure over Ordinary Receipts. £354 1 7

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

F. N. ASHCROFT,
HORACE W. MONCKTON, } *Auditors.*

January 30th, 1924. ROBERT S. HERRIES, *Treasurer.*

Statement of Trust-Funds and Special Funds: December 31st, 1923.

'WOLLASTON DONATION FUND.' TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1923	32	3	8	By Cost of Bronze Medal	1	10	0
" Dividends on the Fund invested in £1073 Hampshire County 3 per cent. Stock	32	3	8	" Award from the Balance of the Fund	21	13	8
				" Difference between the cost of Gold & Bronze Medals, transferred by the Medallist to the Voluntary Publication Fund, and included in the Donations	9	0	0
				" Balance at the Bankers' at December 31st, 1923	32	3	8
	£64	7	4		£64	7	4

'MURCHISON GEOLOGICAL FUND.' TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1923	26	10	4	By Cost of Medal	1	0	0
" Dividends (less Income-Tax) on the Fund invested in £1000 London, Midland, & Scottish Railway 4 per cent. Debenture Stock[1]	30	5	1	" Award to the Medallist..........................	10	10	0
" Income Tax recovered	10	10	1	" Award from the Balance of the Fund	30	0	5
				" Balance at the Bankers' at December 31st, 1923	25	15	1
	£67	5	6		£67	5	6

'LYELL GEOLOGICAL FUND.' TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1923	52	15	3	By Cost of Medal	1	4	0
" Dividends on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	70	7	0	" Award to the Medallist..........................	25	0	0
				" Awards from the Balance of the Fund	44	3	0
				" Balance at the Bankers' at December 31st, 1923	52	15	3
	£123	2	3		£123	2	3

'BARLOW-JAMESON FUND.' TRUST ACCOUNT.

RECEIPTS.	£	s.	d.	PAYMENTS.	£	s.	d.
To Balance at the Bankers' at January 1st, 1923........	23	6	10	By Balance at the Bankers' at December 31st, 1923	37	12	11
" Dividends (less Income-Tax) on the Fund invested in £468 London & North-Eastern Railway 3 per cent. Debenture Stock[2]	10	12	5				
" Income Tax recovered............................	3	13	8				
	£37	12	11		£37	12	11

[1] Formerly £1334 London & North-Western Railway 3 per cent. Debenture Stock.

‘Bigsby Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1923	10	11	1	By Cost of Medal	12	12	0
,, Dividends (less Income-Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	4	16	1	,, Balance at the Bankers' at December 31st, 1923	4	6	8
,, Income Tax recovered	1	11	6				
	£16	18	8		£16	18	8

‘Geological Relief Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1923	70	17	3	By Grants	8	8	0
,, Dividends on the Fund invested in £139 3*s.* 7*d.* India 3 per cent. Stock	4	3	4	,, Balance at the Bankers' at December 31st, 1923	67	7	5
,, Interest on Deposit		14	10				
	£75	15	5		£75	15	5

‘Prestwich Trust Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1923	36	15	0	By Balance at the Bankers' at December 31st, 1923	57	15	0
,, Dividends on the Fund invested in £700 India 3 per cent. Stock	21	0	0				
	£57	15	0		£57	15	0

‘Daniel-Pidgeon Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1923	15	5	8	By Award	30	11	4
,, Dividends on the Fund invested in £1019 1*s.* 2*d.* Bristol Corporation 3 per cent. Stock	30	11	4	,, Balance at the Bankers' at December 31st, 1923	15	5	8
	£45	17	0		£45	17	0

‘Gloyne Outdoor Geological Research Fund.’ Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1923	22	0	2	By Solicitors' Fees	15	18	4
,, Dividend (less Income-Tax) on the Fund invested in £1676 17*s.* 6*d.* $3\frac{1}{2}$ per cent. Conversion Loan (1961) for half-year	44	15	0	,, Balance at the Bankers' at December 31st, 1923	65	10	2
,, Income Tax Recovered	14	13	4				
	£81	8	6		£81	8	6

SPECIAL FUNDS.

Sorby and Hudleston Bequests. (£1000 Stock each.)

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Dividends (less Income-Tax) on the Fund invested in £2000 Canada $3\frac{1}{2}$ per cent. Stock	53	7	6	By Transfer to General Purposes Account	70	17	6
,, Income Tax recovered	17	10	0				
	£70	17	6		£70	17	6

Maintenance Fund

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1923	202	3	11	By Payments during the year	174	2	2
,, Transfer from General Purposes Account	250	0	0	,, Balance at the Bankers' at December 31st, 1923	281	1	3
,, Interest on Deposit	2	19	6				
	£455	3	5		£455	3	5

Voluntary Publication Fund.

	£	s.	d.		£	s.	d.
To Donations and Subscriptions	£420	6	6	By Transfer to General Purposes Account, for the Quarterly Journal	£190	8	8
				,, Balance at the Bankers' at December 31st, 1923	229	17	10
	£420	6	6		£420	6	6

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

ROBERT S. HERRIES, *Treasurer.*

January 30th, 1924.

F. N. ASHCROFT,
HORACE W. MONCKTON, } *Auditors.*

Statement relating to the Society's Property.

December 31st, 1923.

	£	s.	d.	£	s	d.
Balance in the Bankers' hands, December 31st, 1923, being the balance of the Voluntary Publication Fund (£229 17*s.* 10*d.*, less overdraft on General Purposes Account, £74 12*s.* 7*d.*)	155	5	3			
Balance in the Clerk's hands, December 31st, 1923	10	19	8			
				166	4	11
Balance of the Maintenance Fund				281	1	3
Arrears of Annual Contributions .... (Estimated to produce £200 0*s.* 0*d.*)				229	9	0
				£676	15	2

Funded Property:—	Cost Price.			Valued at Dec. 31st, 1923.		
£2500 India 3 per cent. Stock	2623	19	0	1406	5	0
£2540 Southern Railway 5 per cent. Preference Stock[1]	4110	2	9	2489	4	0
£3545 London, Midland, & Scottish Railway 4 per cent. Preference Stock[2]...........	4749	10	0	2818	5	6
£267 6*s.* 7*d.* Natal 3 per cent. Stock	250	0	0	191	2	10
£2000 Canada 3½ per cent. Stock [1930–1950] (Sorby and Hudleston Bequests) ..	1982	11	0	1570	0	0
	£13,716	2	9	£8474	17	4

[NOTE.—*The above amount does not include the value of the Library, Furniture, and stock of unsold Publications.*]

ROBERT S. HERRIES, *Treasurer.*

January 30th, 1924.

[1] Formerly £300 London, Brighton, & South Coast Railway 4 per cent. Preference Stock and £2800 London & South-Western Railway 4 per cent. Consolidated Preference Stock.

[2] Formerly £2250 London & North-Western Railway 4 per cent. Preference Stock and £2072 Midland Railway 2½ per cent. Perpetual Preference Stock.

Award of the Wollaston Medal.

In presenting the Wollaston Medal to Dr. Arthur Smith Woodward, F.R.S., the President addressed him as follows:—

Dr. Smith Woodward,—

It has been my privilege for many years to enjoy the hospitality of the Department with which you have been connected for rather more than four decades. Though only superficially acquainted with the matter of your original investigations, I can appreciate their importance as contributions towards the unravelling of the tangled skein of life in which we are both interested, and I can with sincerity acknowledge the unfailing kindness which you have shown to me, a fellow-worker, though in a different branch of our common science. Ten years after you joined the Staff of the British Museum you were appointed Assistant Keeper, and in 1901 you succeeded Dr. Henry Woodward as Keeper. The award to you of the Wollaston Medal on the eve of the termination of your official connexion with the Museum may be regarded, in part at least, as an expression of appreciation of the greatness of the debt which the National Institution owes to you. The Gallery of Fossil Fishes contains by far the finest collection in the world: its completeness is in large measure due to your energy, ability, and tireless devotion. The four volumes of the Catalogue of this collection, and the surprisingly large number of your other publications, have given you a pre-eminent position as an authority on Vertebrate Palæontology.

I cannot help expressing great regret that the Museum is about to be deprived of the benefits which it has long enjoyed through your unique knowledge of museum arrangement, acquired by visiting nearly all the important collections in the world, added to your mastery of the subject to which you have more especially devoted yourself. May I express a hope that this loss may, in some degree, be compensated by the greatly increased leisure for research which your retirement will provide?

Your association with the late Charles Dawson in the discovery and excavation of the now world-famous Piltdown skull and other human remains was a circumstance for which this Society and the scientific world are grateful.

You have not allowed yourself to be wholly absorbed by the

attraction of research in the narrower and more selfish sense; by your lucidity of expression and ability to speak in a language that can be understood by the layman you have rendered conspicuous service. You have presided with distinction over this Society, the Linnean Society, the Geologists' Association, and other scientific bodies; and as Secretary and Editor of the Palæontographical Society you have earned the grateful thanks of many authors. You have taken a broad view of the duties of a professional man of science; you are one of those

> 'who hath among least things
> An under-sense of greatest; sees the parts
> As parts, but with a feeling of the whole.'

Dr. Smith Woodward replied in the following words:—

Mr. President,—

I wish to thank the Council for the great honour that they have done me in awarding to me the Wollaston Medal, the highest distinction to which a geologist can aspire. If I am indeed worthy of their choice and of all the commendation which you, Sir, have just so kindly expressed, I feel that this is chiefly due to my long and intimate association with the Fellows of the Geological Society. Beginning with my early instructor, Sir William Boyd Dawkins, followed immediately by the late Dr. R. H. Traquair, the Fellows of the Society have continually stimulated me to research, both by their example and by their helpful comradeship. During vacations and in my leisure after official work, I have had unusual opportunities for pursuing one small branch of our science, and it is very gratifying to learn from this token of the Society's approval that I am judged to have achieved some success. I am convinced that, as Vertebrate Palæontology progresses, it will become of increasing value in solving many of the problems of Geology. The time has almost arrived for a new broad survey of the great accumulation of facts which have been gathered during recent years, and I hope that, with the extended leisure which circumstances will soon afford, I may still be able to utilize my long experience, and devote some attention to this subject. Again I thank you, Sir, and desire, in conclusion, to express the pleasure that I feel in receiving this Medal from so old and valued a friend.

Award of the Murchison Medal.

The President then presented the Murchison Medal to Dr. Walcot Gibson, addressing him as follows :—

Dr. Gibson,—

The Council have awarded to you the Murchison Medal in recognition of a long record of good work: I would especially emphasize the value of your researches into the later Carboniferous rocks of England and Wales. After a brief sojourn in South Africa, where you made full use of your opportunities to add to the little that was known of the geology of the Southern Transvaal, you joined the Geological Survey of Great Britain, and began your official work by aiding in the 6-inch survey of the South Wales Coalfield. But it was in the Coalfields of the Midlands, Nottinghamshire, and Yorkshire that you found full scope for your energies. There a classification of the Coal Measures, which had been suggested by previous workers, was established by your 6-inch survey of the North Staffordshire Coalfield. The various subdivisions of the productive and unproductive measures were defined and recognized by you over a wide area in Central England. Your studies of their character and changes in development placed you in a position to attack the difficult problems associated with the existence and accessibility of concealed coalfields. By bringing into co-operation your knowledge of the palæontology and stratigraphy of the later barren Measures you were able to give material help to the Engineer in the exploration of the underlying productive Measures, a service which is of national importance. For work such as yours, which provides firm stratigraphical foundations, a Palæobotanist also may be allowed to express gratitude. I venture to express my confidence that, in the responsible position which you now hold, that of Assistant Director in charge of the Scottish branch of the Geological Survey, your experience will be turned still further to good account.

Dr. Walcot Gibson replied in the following words:—

Mr. President,—

I wish to express my sincere appreciation of the great distinction conferred upon me by the Council of the Geological Society, and for your kindly mention of my efforts.

Much of the work to which you have referred has been possible, only with the aid of information obtained from those employed in coal-mining. I am sure that this recognition will be an encouragement to others engaged in collecting and interpreting the evidence revealed in mining operations, especially in boring and sinking for coal.

In the broad classification of the Carboniferous rocks, and in fixing the boundaries between the later Palæozoic and early Mesozoic formations, the Palæobotanist holds the casting vote. In receiving the Murchison Medal at your hands I gratefully acknowledge that indebtedness.

Award of the Lyell Medal.

In presenting the Lyell Medal to Mr. William Wickham King, the President addressed him as follows :—

Mr. Wickham King,—

You have been described by a colleague better informed than I am as one of a band of enthusiastic workers who, more than thirty years ago, were inspired by the teaching of the late Prof. Charles Lapworth in the classes and field-excursions connected with the Mason College, Birmingham.

Your first paper on the Trappoid Breccias of the Clent Area, published in 1893, was followed in 1899 by a paper on the Permian Conglomerates of the Lower Severn Basin, in which you established for the first time a lithological succession of the Permian of the Midlands, and explained the source and mode of accumulation of its rocks. For nearly thirty years you diligently collected a great mass of facts from mining plans and field-exposures, from which has been constructed an accurate and detailed model of the Thick Coal of South Staffordshire: your researches throw new light on the pre- and post-Carboniferous disturbances in the area covered by the model. You have also discovered and described inliers of Old Red Sandstone Passage-Beds in the South Staffordshire Coalfield.

You have always been eager to help others working in the same field as yourself, and, I am told, your keen eye for a fossil band in most unpromising rocks and your unflagging industry in worrying out a piece of complicated ground have often proved of the greatest value both to yourself and to others.

It is satisfactory to know that exacting professional duties have not been allowed to impair your energy, and I hope that we shall soon hear some account of the work on the stratigraphy and fossils of the Old Red Sandstone of the Severn Valley upon which you have long been engaged.

Mr. Wickham King replied in the following words:—

Mr. President,—

I thank you for the distinction that the Council have bestowed upon me, as a recognition of my efforts to throw some light on problems connected with the interesting district in which I have dwelt all my life.

Many kind friends, and nearly all the mining engineers and colliery proprietors in South Staffordshire, have helped me enormously. Without this generous assistance the enquiry into the folding and floor of that coalfield would not have materialized, as this work was indeed abandoned for lack of the necessary materials, although later on they were forthcoming.

The advantage derived from the teaching, friendship, and inspiration of Prof. Charles Lapworth cannot be overestimated. He sowed the seed, and his students' results are the products of his master mind.

I thank you, Sir, for your kind appreciation of my work. I hope to continue it, and thus perhaps justify this unexpected honour.

Award from the Wollaston Donation Fund.

The President then presented the Balance of the Proceeds of the Wollaston Donation Fund to Dr. Cecil Edgar Tilley, addressing him as follows:—

Dr. Tilley,—

Equipped with a sound working knowledge of chemistry and petrography, you set yourself to study some of the many interesting problems presented by metamorphism, both regional and local. The gneisses and other crystalline rocks of your native South Australia provided material which you successfully used in your thesis for the Doctorate at Cambridge, and to this you added

an investigation of the crystalline schists of the Start district in South Devon, which appeared in the Quarterly Journal. You have also described, for the Australian Antarctic Expedition, an interesting series of marbles and calc-schists collected in Adélie Land by Sir Douglas Mawson. Subsequently you examined the contact-metamorphism of the schists and grits surrounding the diorite intrusions of Carn Chois, near Comrie. Your study of these rocks, presented to this Society last June, but not yet published, will, I am assured, take its place as a contribution of real and permanent value. You have followed the sound practice of combining conscientious work in the field with thorough investigation of material in the laboratory; and, conducted on these lines, your researches may be expected to achieve equally happy results in the future.

Award from the Murchison Geological Fund.

In presenting the Balance of the Proceeds of the Murchison Geological Fund to Dr. Leonard Frank Spath, the President addressed him in the following words:—

Dr. Spath,—

The study of Ammonoid Cephalopods is a task which, in these days, few would lightly undertake. Its literature is immense and widely scattered: its terminology—I had almost said, its jargon—is crabbed: and, even if attention is confined to the representatives of a single formation, its material is bewildering in its protean variation and in the rapid succession of differing yet similar forms. Moreover, previous workers in the same field can hardly be said to have lightened their successors' labours. Yet you have not hesitated to take up the burden. You early mastered the voluminous literature. You have been able, in consequence, to deal with Ammonoid Cephalopods from many formations; and thus, instead of specializing narrowly, your view is wide enough to give particular value to your conclusions. Nor have you confined your activities to the study. By careful collecting in the field you have checked your systematics by evidence gathered from the actual occurrence of the material. In particular, you have paid attention to the Lias Ammonites, rendering possible the correlation of beds so far apart as the Dorset coast and the Hebrides; and, by tracing

their ontogeny in detail, you have elucidated the phylogeny of certain forms. You have also recently published an important paper on the Ammonites of the Speeton Clay.

Your published work has made it clear that you are not in agreement with some of the modern developments of evolutionary thought; but it is to be hoped that you will not let your commendable caution prevent constructive ideas on organic evolution from ultimately appearing in your systematic work.

Awards from the Lyell Geological Fund.

The President then presented the Balance of the Proceeds of the Lyell Geological Fund to Mr. John William Tutcher and to Mr. Hugh Hamshaw Thomas, addressing them as follows:—

Mr. Tutcher,—

A Moiety of the Balance of the Lyell Geological Fund is awarded to you in recognition of your work on the Jurassic and Rhætic strata of the South-West of England. By studies which are characterized by scrupulous accuracy and thoroughness, you have gained a high position in the ranks of a distinguished body of geologists who have devoted themselves to the interpretation of Jurassic history. I would, in particular, mention a paper on Zonal Sequences in the Lower Lias published in this Society's Journal. You have not only made valuable contributions to our science as a field-geologist, but, by generously placing your experience and skill at the disposal of colleagues, you have gained additional recognition as an exceptionally successful scientific photographer. I am told that, between the years 1903 and 1920, more than two thousand of your photographs of fossils have been reproduced in books and contributions to scientific periodicals.

The call of Natural Science is sometimes heard with greater effect by those who devote to the pursuit of knowledge the precious intervals of leisure in a business-life than by men who are professional geologists. It is an especial pleasure to me to hand to you this mark of recognition of your scientific researches, and of gratitude for the help which you have always been ready to give to your fellow-workers.

Mr. Hamshaw Thomas,—

For the second year in succession a Palæobotanist has been selected as the recipient of an award, a decision with which I am naturally well pleased, the more so because of our association as members of the same University Department and of the same College. After publishing an important paper on the foliage of Calamites, a paper in which Palæozoic plants were treated not as mere petrifactions, but as living organisms absorbing light and transpiring water, you spent the greater part of your leisure in the collection and investigation of the rich stores of material furnished by the Jurassic rocks of Yorkshire. Researches already published have won for you an assured position in the botanical world. By your intensive study of cuticular membranes, you have been able to provide trustworthy data on which to base a natural classification of the several types of Cycadean fronds. One of the most interesting of the many contributions which you have made to Jurassic Botany is the discovery in the famous Gristhorpe Beds of a new genus of Gymnosperms, which you named *Williamsoniella*, represented by stems, bisexual flowers, and probably bearing *Tæniopteris* leaves. The preliminary accounts which you have given of the most exciting of your successes, the discovery in Jurassic shales of fruits filled with tightly packed seeds, which appear to demonstrate the existence of Angiosperms at a time considerably earlier than that to which they are usually assigned, make us look forward with eagerness to the publication of a full description of your researches. You have raised expectations of results which may help to solve what Darwin aptly called that 'abominable mystery', the origin and early history of the Flowering Plants.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

ALBERT CHARLES SEWARD, Sc.D., F.R.S.

BEFORE pursuing to its later stages the subject selected for my Address last year I should like to seize the opportunity of wishing my successor in this chair as happy an occupation as I have enjoyed. Dr. Evans will do more for the Society than I have done: he has a breadth of knowledge which has often awakened in me feelings almost of reverence and friendly envy. He will be articulate when I, through sheer ignorance, have often been silent.

A President's peace of mind is, to a considerable extent, in the keeping of the Officers; for his conscience he alone is responsible. A President is in an exceptionally favourable position for forming a just estimate of the extent and value of services given by his colleagues: a Society which is as well served as is ours may confidently look forward to the future. It is in no invidious sense, as his colleagues well know, that I offer special thanks to Mr. Campbell Smith, who has not only watched over me here, but has regularly visited me at Cambridge; he has always been ready to undertake work which I ought to have done, and by his knowledge of affairs and sanity of judgment he has given me confidence that has made a difficult task not only easy, but invariably pleasant. I would also express my indebtedness to the Fellows as a whole, and particularly to those who have contributed biographical sketches of Fellows whom we have lost during the year. Prof. Fusakichi Omori, of the Seismological Institute of Tokyo, one of our Foreign Correspondents, died in November of last year. We miss the familiar presence of Sir Henry Howorth, whose researches extended far beyond the boundaries of Geology. The tragic death of Sir Henry Hayden in the full vigour of his life is a grievous loss to Science, and to a wide circle of friends. A Fellow for more than sixty years, Prof. Thomas George Bonney died in December in his ninety-first year. Prof. Bonney was Secretary of the Society from 1878 to 1884, and President from 1884 to 1886. He used to speak with pride of the generations of students whom he had initiated into the mysteries of Geology: our Society is proud to count him among the great ones of those who have occupied the President's chair. He was a scholar in the fullest sense; a man of strong convictions and high ideals. His

honesty, and perhaps sometimes his prejudices, occasionally got the better of his regard for the delicate susceptibilities of others; but those who were privileged to know him as a friend not only respected and admired the compass of his learning and his virile personality, but felt for him an affectionate regard. His erudition and scholarship were beyond the range of many of us: his essentially human qualities brought him into close touch with us all.

John Ballot, an Afrikander of Scottish parentage, was one of the pioneers of the Rand mining industry and one of the earliest to take an interest in the geology of that district. He initiated in the local press a controversy on the origin of the gold in the 'banket', which has not been settled to this day. Later, he came to London, and, as Chairman of the Minerals Separation Company, rendered valuable service to the mining world by the commercial development of the 'flotation' process for the separation of complicated sulphide-mineral aggregates and the recovery of the more valuable constituents. He had been a Fellow of our Society since 1898. [F. H. H.]

By the death of Thomas George Bonney on December 9th, 1923, one of the last links with the heroic age of Geology is severed. He was born in 1833, when the first edition of Lyell's 'Principles of Geology' was appearing, and during his lifetime he witnessed a remarkable advance in the science, in which he himself took no inconsiderable share.

Prof. Bonney was a man of many parts, geologist, naturalist, theologian, journalist, author of many books on divers subjects, and, we may venture to add, artist: it would be impossible to give an account of his varied career in the short space here available; indeed, in that space it is not easy even to summarize his contributions to his favourite science.

Shortly before his death he published a small book of reminiscences, entitled 'Memories of a Long Life'. From this can be gathered some account of his many activities, and a general notice of his geological work appeared in the 'Geological Magazine' for 1901, as one of the articles devoted to 'Eminent Living Geologists'. The bibliography attached to this memoir covers six pages of small type: from this can be gauged the extent of his contributions to Geology alone, for no mention is there made of publications on other subjects.

Prof. Bonney's geological work may be considered under the three headings: original research; teaching; and summarizing the conclusions of others.

Among the earliest of the very long list of his publications were several papers dealing with glacial problems and the origin of cirques, but he soon turned his attention to Petrology, at first chiefly to the microscopic structure of the igneous rocks; while, at a later date, he worked largely on the metamorphic groups. The results of researches in these two fields, so far as they had then been carried, were summarized in Presidential Addresses to the Geological Society in 1885 and 1886, while the address to Section C of the British Association at Birmingham in 1886 gave an admirable account of the microscopic characters of British sediments. Among his researches on igneous rocks of the British Isles, which covered a very wide field, special mention may perhaps be made of the papers dealing with the pre-Cambrian rocks of North Wales, the Charnian rocks of Leicestershire, and the Lizard complex of Cornwall: throughout his life Prof. Bonney was always much interested in serpentine-rocks both at home and abroad, and devoted much attention to the characters and origin of this group. On account of his proficiency in microscopic petrology, many travellers in remote regions entrusted to him for identification and description the rock-specimens collected by them, and altogether the number of now well-known rocks, both British and foreign, first described by Prof. Bonney, is very large.

Two brief addresses delivered by him as President of the Mineralogical Society dealt with prevailing tendencies in Mineralogy, and emphasized the importance of synthetic methods of research.

He was always much interested in the subject of coral-reefs, and contributed an appendix to a later edition of Darwin's great work on the subject: also, as Chairman of the Coral Reefs Committee appointed by the Royal Society, he devoted much time and energy to the work of the expeditions sent out to investigate the structure of Funafuti, from which valuable results were obtained.

It is perhaps unfortunate that much of his work on the crystalline schists was done in Switzerland, where the problems are peculiarly complex; but he accomplished much where most men would have been completely bewildered. He was especially interested in the pre-Cambrian rocks, and was one of the first to recognize the true age of the complex of the North-West Highlands.

Of purely stratigraphical work he published little, but often generously gave his results to others, as for instance in the case of the Cambridge Greensand. He had, however, a particular affection for the Triassic rocks on which he was born, and paid special attention to the source of origin of the pebbles of the Bunter Series.

In Physical Geology he was keenly interested in glaciation, and always opposed what he regarded as the extreme views of more modern glaciologists. His final position in this matter was put forward in his Presidential Address to the British Association at Sheffield in 1910.

As a teacher he achieved great success: he always recalled with pride the long roll of pupils at Cambridge and in London who had passed through his hands, and who in some cases had been induced by him to begin the study of the science. He was probably the first systematic teacher of Petrology in this country, but his lectures covered the whole field of the science. They were singularly clear and stimulating; quite devoid of any embellishments, yet very easy to follow: those on Palæontology, for instance, showed that he knew exactly what the student required.

His general writings on such subjects as rivers and volcanoes attract alike the scientific and the non-scientific reader.

His love for the Alps was intense: again and again he returned to them, in later years usually accompanied by his devoted friend, Canon E. Hill. He was interested not only in their geology but in everything connected with them, and, as he was no mean climber, it was natural that he should be called upon to occupy the Presidential chair of the Alpine Club.

It is needless to enumerate the many honours which he received. Records of most of them will be found in the article in the 'Geological Magazine' already cited. He served the Society well, being a Member of Council for 29 years in all and Secretary for four years: he held the Vice-Presidency four separate times and was, of course, President (1884–1886). He had been a Fellow of our Society since 1860.

'As in private duty bound', we would say a few words concerning what he did for geology at Cambridge. The results of his teaching at his own college of St. John's are well known, but in his latest years he resumed his teaching as an informal Demonstrator at the Sedgwick Museum, and this was very highly appreciated by staff and students alike. His love for his University was indicated by

the gift, during his lifetime, of his magnificent collection of rocks and rock-slices to the University.

Of the man himself we would say something. With his strong character he was bound to be a leader in any society of which he was a member. Of medium height, his dignified carriage suggested a stature greater than he actually possessed. His courtesy of manner was very great, and he represented a type of University don which is now, alas! rapidly disappearing. He did not suffer fools gladly, and on occasions he was sharp with both tongue and pen. This made him enemies, and it is to be feared that he suffered more by these defects than did others. His failings were but superficial and hid from the casual observer his true nature, which was marked by an unselfish and exceeding kindliness, known to many and especially to those in trouble.

A really great man has passed away; and the world, not only the world of science, is the poorer by his loss. [J. E. M. & R. H. R.]

William Stukeley Gresley, who died in November last at the age of 73, was elected a Fellow of this Society as long ago as 1877; he was also an Associate-Member of the Institution of Civil Engineers and a Member of the Institution of Mining Engineers. He acted as consulting mining engineer to several collieries in the Midlands, and, besides publishing a 'Glossary of Terms used in Coal-Mining' (1883), he contributed several articles to the 'Colliery Guardian' on the correlation of the Coal Measures.

Between the years 1885 and 1894 he read six papers before our own Society, the best known of which, perhaps, is that on 'Cone-on-Cone', published in vol. l of the Quarterly Journal.

His eldest son was killed in the Great War, and he leaves two younger sons to mourn his loss.

By the death of Frederic William Harmer on April 11th, 1923, our science has lost one of the pioneers among the band of distinguished amateurs to whom Geology owes so much. Born on April 24th, 1835, Harmer came of an old Norfolk family, and by his public services was prominently identified with the City of Norwich. In his early years he had only the scanty leisure of a strenuous business life to devote to Geology, but the interests which he thus formed were a continual incentive to scientific work, and proved a comfort after the loss of his wife and in his old age.

A chance meeting with the younger Searles Wood, on the Mundesley shore in 1864, was the beginning of a firm friendship and of a long-continued geological partnership. Together they studied the Pliocene deposits, the fauna of which was then being described in the Monographs of the Palæontographical Society ('The Crag Mollusca') by Searles Wood the elder. The Drift deposits also engaged their attention, and, between them, the two surveyed an area of 2000 square miles, Harmer undertaking the survey of Norfolk and Northern Suffolk. Their map, produced on a scale of 1 inch to the mile, was claimed to be the first 'drift' map of the kind. Then came the illness and death of the younger Searles Wood, in 1884, and Harmer felt the blow so severely that, as he was wont to say, he had no heart to continue the work alone. He devoted himself, therefore, to municipal duties and to the politics of the day, until a sharp disagreement with his party on the question of Irish Home Rule caused him to apply his energies whole-heartedly to Geology. He then began an intensive study of the Tertiary and Quaternary deposits of East Anglia and the Continent. The preliminary accounts of the work on the Red and Coralline Crags, read before the British Association at Ipswich in 1895, began a new régime in East Anglian geology. A few years later some further results of his work were published in our Quarterly Journal. His ascription of all the Coralline Crag deposits to the same geological age, and the division of the Red Crag into horizons which indicate the northward retreat of the Pliocene sea, are now generally accepted. Later he turned his attention to a comparison of the Pliocene sequence in Britain with that in Holland and Belgium. About this time also he studied the wind-drift during Crag times; and this led to an interesting discussion of the palæo-meteorological conditions during the Pleistocene epoch.

In more recent years Harmer began the heavy task of bringing up to date the Monograph of the Crag Mollusca. His intensive collecting from the richly fossiliferous deposits at Little Oakley, near Harwich, had added much to the material awaiting study since the publication of Searles Wood's third Supplement in 1882. To the description of these shells he devoted the last years of his life, and the completion of this heavy task (shortly before his death) was a source of much satisfaction and relief to him.

This Monograph completed, he had even further work in view, for it was his intention to return to the study of glacial problems.

From time to time, while engaged on the description of the Crag shells, he published papers on the glacial deposits of the East of England, and on the evidence of glacial lakes and cañon-valleys in various parts of the country. His last contribution (at present in course of publication) is a detailed map showing the types of Boulder Clay and the trails of the various erratics throughout England.

Recognition both at home and abroad naturally followed the publication of Harmer's work. He was elected an Honorary Member of the Geological Society of Belgium in 1905, and the University of Cambridge conferred on him the honorary degree of Master of Arts in 1917. He became a Fellow of our Society in 1869, served on the Council from 1896 until 1901, and the Murchison Medal was awarded to him in 1902. [P. G. H. B.]

Sir HENRY HUBERT HAYDEN, who was born at Londonderry in 1869, and was Director of the Geological Survey of India from 1910 to 1920, was killed in the Alps last year. Although the precise details of the accident are unknown, it is fairly certain that Hayden and his two guides were carried away by a rock-fall or avalanche soon after the 12th of August, 1923, on their return from a successful ascent of the Finsteraarhorn. Their bodies were found on the western face of the mountain on August 28th, and Hayden was buried at Lauterbrunnen on September 1st.

Those who had the great privilege of knowing him with real intimacy realize that, if Hayden had been able to choose the way of ending his career, it would have been on a mountain-side, in some fight against physical difficulties and in an attempt to save the life of a companion.

A complex of qualities such as those which endeared him to friends in many unlike types of society is rarely found so successfully blended in one individual. As an undergraduate, his most obvious bent was in a classical direction; but, after taking his first degree at Trinity College, Dublin, he remained at the University to take another degree in engineering, and only afterwards turned his full attention to Geology.

He joined the Geological Survey of India on January 3rd, 1895, and, during the 25 years' service that followed, his activities justified the breadth of his early training; for he touched most of the recognized boundaries of his adopted subject. His first paper dealt with the microscopic features of some igneous rocks, and,

after two or three years of miscellaneous work, mainly mineralogical and economic, he found his real opportunity as a mountaineer in the survey of the stratigraphical formations of Spiti in the North-Western Himalaya. Later stratigraphical work of a similar nature in Afghanistan and on the North-West Frontier, in Eastern Tibet and Kashmir, was interrupted occasionally by curious difficulties which involved questions in physical geography and the application of geology to problems of civil engineering.

Hayden's papers on all these branches have appealed to specialists in each as the products of a worker who manifestly had mastered the principles, and had dug deeply into the literature of his subject; but his stratigraphical work in the Himalayan region stands out as that which must have the widest influence on students of geomorphology.

His first important memoir on this subject was a descriptive account of Spiti and Bashahr. In this essay he was hampered by the tendency then prevailing to apply the nomenclature of the European standard scale directly to Indian formations. The next most important instalment towards the solution of Himalayan problems was his memoir on Central Tibet, when he proved the eastward continuation, along the northern face of the snow-covered range, of the great marine basin already known in Spiti and Kumaon. In 1907–1908, Hayden, in collaboration with Sir S. G. Burrard, published what the two authors modestly called a 'Sketch of the Geography & Geology of the Himalaya Mountains & Tibet.' The aim of this work was 'popular', and its clear descriptions, assisted by abundant illustrations, justify the term; but, as a discussion of the great variety of questions involved, with its numerous references to literature, and the inclusion of results not separately published, this memoir forms an important contribution to scientific literature. In it Hayden revealed the tendency of the Geological Survey to revert to the more cautious, more scientific, policy followed by Thomas Oldham, H. B. Medlicott, and the early workers who brought order into Indian Geology, to use local names for natural groups of strata, putting into its correct position of subordination the problem of correlation with European formations and of translation into terms of the standard scale of nomenclature.

Later, in Afghanistan, he added a third instalment to the data necessary to form a connected history of the evolution of physical geography in this remarkable region.

In the absence of sufficient data, Suess and Fütterer had attempted to piece together the isolated facts regarding the tangled orographical knot forming the North-West Himalayan region by assuming the existence of anomalous trend-lines for the junction between the Himalayan and Iranian arcs. On this point Hayden remained always sceptical; but it was not until early in 1914, when long furlough from the Indian official service was due, that he found an opportunity of exploring Central Asia, in the hope of correlating his work in Afghanistan with that accomplished in Kashmir and the Himalaya. His results, which are recorded in a highly condensed paper in the Records of the Geological Survey of India (vol. xlv, pt. 4, 1915), showed that the general strike of the rock-folds and the trend of the dominant orographical features coincided, forming a curve parallel to that of the great re-entrant bay of the Himalayan foot between the meridians of 70° and 77°. There is little doubt that this paper will be regarded by students of geomorphology as the most important of Hayden's contributions to geological literature.

At the end of his tramp through Central Asia, Hayden found, on entering Europe, that the Great War had commenced, and his intention of emerging by way of Constantinople had to be changed hurriedly into the longer journey across Russia and, by way of Sweden, home.

In the following year the Geological Society (of which he had been a Fellow since 1900) awarded to Hayden the Bigsby Medal, and the Royal Society elected him a Fellow; while, on his return to India, the Calcutta University conferred upon him the honorary degree of D.Sc. In 1911 his official services were recognized by the conferment of the C.I.E., and in 1919 he received the senior order of C.S.I. In June 1920, on the day of his embarkation at Bombay, preparatory to retirement from the service, his knighthood was gazetted.

His death last year at the age of 54 came as a shock to more friends than any single one of them can enumerate; for his acts of generosity extended to many beyond the community of science. No one knew more than a fraction of them; he kept no receipts: as in his scientific work, each act of kindness was quickly superseded by the next and was apparently forgotten. [T. H. H.]

The Honourable Sir William Herbert Herries, K.C.M.G., who was elected a Fellow in 1885, was born in London on

April 19th, 1859, and died at Wellington (New Zealand) on February 22nd, 1923. He was educated at Eton, where he won the School prize for Geology, and at Trinity College, Cambridge, where he took honours in Natural Science. A few months after taking his degree, he left England for New Zealand, and started farming in the North Island. After making his mark in local affairs, he was in 1896 asked to stand for Parliament. He was returned and continued to sit until his death, having been re-elected on eight occasions. His constituency included the celebrated 'Hot Lake' district with all its natural wonders. During the long period of Liberal ascendancy, marked by the premierships of the late Mr. Seddon and Sir Joseph Ward, he was one of the most prominent members of the Opposition, and, when the turn of his party at last came in 1912, he became Minister of Railways & of Native Affairs under Mr. Massey. He remained a member of the Government up to the time of his death, though, owing to the state of his health, he resigned his portfolios in 1921, when he paid a visit to England. He was perhaps the most popular man in New Zealand: for, although he was a keen fighter, he never made an enemy, and was trusted alike by his supporters and his opponents. His love of sport also commended him to the New Zealand people. He was especially beloved by the native race, and, when the Prince of Wales visited New Zealand in 1920, Herries was responsible, as Minister, for collecting some five thousand Maoris to give the Prince a welcome at the native centre of Rotorua. In that year he was made a K.C.M.G.

Herries was interested in Geology from early boyhood. Going every summer to Yorkshire, he and his brother made a large collection of fossils from the Speeton Clay to the Lias, working on the latter with the then newly published monograph by Tate and Blake. Before he left England his home was at Frimley in Surrey, and he had the opportunity, with his friend Mr. H. W. Monckton, of examining two newly opened railway-lines, one from Brookwood to Aldershot, and the other from Frimley to Ascot. He found a large number of fossils in the Upper Bagshot (Barton) Beds, previously supposed to be practically barren, and established a new locality for the fossiliferous beds of the Middle Bagshot (Bracklesham). He embodied the results of his work in a paper in the 'Geological Magazine' for 1881, and, although this was the only paper that he ever wrote, it was the forerunner of a considerable amount of literature concerning the Bagshot Beds, to which Mr. Monckton, Mr. J. Starkie Gardner, the late Dr. A. Irving,

and others contributed. He had little opportunity of working at geology in New Zealand, but he never lost his interest in the science; and, on his rare visits to England, he would spend much of his time working at his Yorkshire collections, more especially on the Liassic belemnites. It may be added that he was fortunate enough to have seen the famous Pink and White Terraces of Lake Rotomahana, which were destroyed in 1886, and wrote home a most interesting description of them, as he also did of the eruption of Mount Tarawera which caused their destruction. [R. S. H.]

Reginald Walter Hooley, who died on May 5th, 1923, aged 57, was elected a Fellow of our Society in 1904. While engaged in business in Winchester and taking a prominent part in the public life of the city, he devoted his remaining leisure to the study of the geology of the Isle of Wight and to the collection of fossil reptiles and fishes from the Wealden cliffs between Brook and Atherfield. In the small museum which he built adjoining his house at Winchester he prepared his specimens with great skill and patience, and at the same time studied them with scientific thoroughness. He acquired an excellent knowledge of the osteology of reptiles, and made himself so well acquainted with the Mesozoic reptiles that he was able to interpret and describe his Wealden specimens and make them available for science. He described new Wealden Chelonia in the 'Geological Magazine' in 1897 and 1900; and he contributed his first paper to the Geological Society in 1907, when he gave an account of a unique specimen of the marsh-crocodile *Goniopholis*, which added much to our knowledge. He next described a nearly complete specimen of the pterodactyl *Ornithodesmus*, in a paper which was published in our Quarterly Journal in 1913. At the time of his death he had just completed a well illustrated account of a nearly complete skeleton of *Iguanodon*—in some respects the finest known—which was read to the Society posthumously in November last, and will shortly appear in the Quarterly Journal. The specimens of *Goniopholis* and *Ornithodesmus* are already in the British Museum, and it is gratifying to know that the rest of the collection will soon be added to them. Mr. Hooley was also much interested in flint implements and other remains of early Man, and in 1922 he contributed an important paper on the old Solent river and sea to the Proceedings of the Hampshire Field Club. His untimely death is a great loss to geological science, and is mourned by a large circle of devoted friends. [A. S. W.]

In the death of Sir HENRY HOYTE HOWORTH, K.C.I.E., the Society has lost one of its oldest members—a typical Victorian, who was prominent at our meetings, not so much for his original communications as for his acute criticisms in debate—mostly just, always good-humoured, and generally based on a wide knowledge. He will long be remembered by geologists for his opposition to the glacial theory, in which he indicated the weak points with forensic skill and with an extraordinary facility of language. At the end of his life he was engaged in bringing out a second edition of his book 'The Mammoth & the Flood'. He also maintained his belief in the old theory of a deluge that overwhelmed Euro-Asia suddenly, and to which he attributed the presumed glacial phenomena. He was critical rather than original, but never failed to throw light on his subject from various and unexpected sources. With him Geology was only secondary to the many other branches of knowledge to which his life was devoted.

Howorth was born at Lisbon in 1842,—his father belonging to an old Lancashire family—and he was educated at Rossall School, where the writer remembers him as a boy with a love of reading almost everything that was not in the curriculum, and devoid of any interest in games. Afterwards he studied law, and was called to the Bar by the Inner Temple in 1867, but he never took his profession seriously, and was often wont to congratulate himself on having had only one client! His interests lay in other directions, and it was natural that his active mind should be attracted by politics. In 1886 he was elected to Parliament as Conservative member for South Salford—a seat which he held for fourteen years. He took his share in the business of the House, and was extremely useful in keeping the Members awake by his *jeux d'esprit* during the all-night sittings at the time of the Parnell controversy. His political opinions, however, were mainly expressed in a series of letters to the 'Times' on current topics, in which he showed that he was no mere party-man. His heart, however, was not in politics any more than in law, and his main attention was given to matters historical, archæological, and scientific. In 1892 he received the K.C.I.E. for his contributions to the history and ethnography of Asia, and in the following year he was chosen Fellow of the Royal Society in recognition of his work. He was honorary D.C.L. of Durham University, and was appointed Trustee of the British Museum in 1899. He belonged to most of the scientific and literary societies in London, and died

as President of the Royal Archæological Institute. He had joined the Geological Society in 1891.

His numerous contributions to science and literature began in 1868 with a paper read before the British Association, and they reached a total of more than one hundred, published in various journals. He also wrote in the Quarterly and Edinburgh Reviews. His books are many. 'The History of the Mongols from the 9th to the 19th Century' extends to four volumes, and is a surprising work on a difficult subject, involving the study of Russian, Persian, and Indian documents, as well as French and German. It is the only standard work now accessible to ordinary students. He also wrote a scholarly book on Gregory the Great, and followed it up by a companion volume on 'Augustine the Missionary', in which he dealt with St. Gregory's Mission to England, and later carried the story on in a third volume entitled 'The Golden Days of the Early English Church'. His chief geological books were 'The Mammoth & the Flood', 'The Glacial Nightmare & the Flood', and 'Ice & Water'. His energy was as striking as his versatility, and he lived a full life,—happy in his family and in his innumerable friends. [W. B. D.]

William John Le Lacheur, M.A., was elected a Fellow of this Society in 1899. He entered Trinity College, Cambridge, and in 1898 graduated, taking Geology in Part II of the Natural Sciences Tripos in the following year.

After leaving Cambridge he adopted a business career, but his love of Geology led him to spend such leisure as was his in the pursuit of the science.

He had learned much of the geology of Costa Rica, and in later years was greatly interested in the problems connected with river-drainage, especially among the Chalk Downs and in Wales. He freely imparted his knowledge to others, and the results of his scientific work will not be altogether lost. He took many admirable photographs, illustrative of his geological work.

Le Lacheur had a keen sense of humour and great personal charm, which endeared him to a host of friends. Had he lived, he would undoubtedly have done much more geological work of value, and he set an example to others, showing that scientific work is not incompatible with arduous business pursuits.

He died on May 2nd, 1923. [J. E. M.]

Fusakichi Omori was born in 1868; he died on November 8th, 1923, after having occupied the Chair of Seismology in the Imperial University of Tokyo for twenty-seven years. Dr. Charles Davison, in an appreciative notice of his Japanese colleague, writes: 'Few students in any branch of earth-physics have worked harder than Omori, and not many to better purpose. . . . He was one of the most kindly, modest, and upright of men, courteous with that courtesy that we now call old-fashioned.' Omori's first important contribution, published in 1894, contains a statement of his well-known law relating to the decline in frequency of the after-shocks of earthquakes. He made a large number of personal observations in different regions of the world where destructive earthquakes have occurred, and played a leading part in advancing the science of Seismology. Unfortunately, he did not live long enough to contribute an account of the most destructive earthquake of modern times. He had been elected a Foreign Correspondent of our Society in 1912.

Joseph Wright, well known as an authority on recent and fossil foraminifera, died at his residence in Belfast on April 7th, 1923, at the advanced age of 89 years. He had been elected a Fellow of the Geological Society in 1866, and his patient researches were honoured by the award of the Barlow-Jameson Fund in 1896. His parents were members of the Society of Friends, and his early upbringing in the tolerant outlook prevalent in such families in Cork brought him a welcome from all sections of the community on his removal to business in Belfast at the age of 34. He had already gathered a fine collection of Carboniferous fossils, now in the British Museum, and in Northern Ireland he devoted himself to the study of foraminifera, mounting and cataloguing his material with exquisite care, so that others who came after him should find it available for their work. This extensive series of preparations is preserved in the National Museum in Dublin. His daylight-time was mostly at the command of others; but, on occasional holidays, he made himself thoroughly acquainted with the geology of the country round Belfast, and he was able to join in dredging expeditions off the Atlantic coast organized by the Royal Irish Academy. His accurate observations and their wide range brought him correspondence from all parts of the world, and it would have surprised many of his scientific colleagues on the continent of Europe to find, had they visited him in Belfast,

that he was not attached to a learned institution, but spent the greater part of his active life as foreman to a business firm. He was a constant supporter of the Belfast Naturalists' Field Club and of the Belfast Natural History & Philosophical Society. His published work includes papers on foraminifera found in the Chalk and in the northern boulder-clays, and his success in separating delicate specimens from the latter deposits in localities far above the present sea-level made him a persistent advocate of the theory of Pleistocene submergence as against that of glacial uplift. To visit Wright on an evening in his own home, when he was settling down to the work that he loved, among his books and specimens, was a lesson in largeness of heart and a stimulus to research that will not readily pass away. [G. A. J. C.]

THE LATER RECORDS OF PLANT-LIFE.

Upper Devonian Floras.

A year ago I endeavoured to sketch the salient features of the earliest records of Plant-life, from the problematical remains in pre-Cambrian rocks through the older Palæozoic periods to the vegetation of Middle Devonian swamps. The contrast between the Lower and Middle Devonian floras was emphasized, and attention was drawn to the much richer and more definitely terrestrial Upper Devonian floras.

It is no new experience to realize the impossibility of completing a self-imposed task, or to find that performance lags behind intention. The complete fulfilment of my too ambitious project must be postponed to another season and to another method of presentation.

To-day my aim is to deal with some of the problems, suggested by a comparative study of fossil floras, which are more especially connected with geographical distribution, climates of the past, and evolution. A useful purpose will have been served if, by premature expression of opinion based on incomplete data, attention is directed to the need for fuller information and to the importance of taking stock of such knowledge as we already possess.

Before proceeding to describe the more obvious characteristics of the later Palæozoic floras, I propose to intercalate a brief account

of two contributions to our knowledge of the Middle Devonian flora of Scotland. Reference was made in the review of the older Devonian floras to a plant discovered by Hugh Miller near Cromarty, and afterwards named by W. R. McNab *Palæopitys Milleri*. It was stated that the original specimen was being investigated by Dr. R. Kidston & Prof. W. H. Lang: the results of their work have now been published. The type-specimen consists of a piece of stem with a badly-preserved solid primary axis of tracheids, pitted on all their walls, surrounded by a woody cylinder slightly more than 2 cm. in diameter, composed of radially disposed tracheids with multiseriate pits and medullary rays. Of the appendages of the stem we know nothing. *Palæopitys* proves the existence in a Middle Devonian flora of a plant having the power of secondary growth in thickness; but the anatomical features now revealed show that it differs from all known examples of the higher Gymnosperms. We have no proof that it bore seeds; it may, as the authors suggest, be a member of some archaic group of Gymnosperms or, possibly, its affinity may be to the group Pteridophyta.

Another addition to the list of Middle Old Red Sandstone plants, for which we are indebted to the same authors, is *Hicklingia Edwardi*. The type-specimen consists of numerous linear, forked axes diverging from an obscure basal region: the swollen tips of several branches are interpreted as terminal sporangia. In the presence of a slender axial strand and in the absence of leaves, *Hicklingia* agrees with the genera *Rhynia* and *Hornea* previously described. It may be an Alga, or possibly a simple form of Pteridophyte. The probability is that it was either a water-plant, or one which had not become completely adapted to life on land.

The vegetation of the Upper Devonian Period persisted without any drastic change into the succeeding Carboniferous Period. In some parts of the world geologists have experienced considerable difficulty, when a few fossil plants are the only available records, in strictly delimiting one period from the other. Instances of the absence of a well-defined dividing line are afforded by certain strata in Australia. Similarly, in South Africa, there are sedimentary rocks attaining a very great thickness, in which imperfect plant-remains have been discovered that cannot be allocated to a precise geological horizon. One fact stands out clearly: in Devono-Carboniferous days—by this I mean Upper Devonian and Lower Carboniferous days—certain genera flourished well within the

Arctic Circle and in the southern part of the great Gondwana continent. Palæobotanical evidence points to the existence of a far-flung vegetation of a fairly uniform facies. *Archæopteris*, those fern-like fronds which were probably not fronds of true Ferns, as we have already seen occurs as far north as lat. 80° N. and is recorded also from many European localities and Australia. When we pass to the Upper Carboniferous Period a different state of affairs is revealed.

It is not my intention to describe in detail the vegetation which flourished during the later stages of the Devonian Period; my aim is to follow the main lines of development of the terrestrial succession and to draw attention to some of the problems that are presented by a comparative survey of the more prominent facts. Special consideration will be given to geographical distribution in its wider aspects, including Palæoclimatology, and account will be taken of some of the many disturbing considerations which confront the student of Evolution.

Associated with the well-marked differences between the older Devonian floras and those preserved in Upper Devonian rocks, we can recognize some connecting links. The Lepidodendroid plants, to which reference was made last year, from South America, Africa, Australia, and elsewhere are represented in the later Palæozoic floras by *Cyclostigma*, *Lepidodendron*, and allied genera. The large Sphenopteroid fronds from Bear Island, Belgium, and other parts of Europe are doubtless direct descendants of older Devonian forms. As the branched shoot-system became more attuned to life on land, a clearer distinction was introduced between axis and leaflet. While some of the differences between the earlier and the later Devonian types may be the expression of progressive evolution tending towards a fuller division of labour in tissues and members, it is probable that the contrast is, in large measure, the result of a changed environment. The swamp flora of the Lower and Middle Devonian stages was gradually transformed into a flora that was more completely terrestrial. As continental conditions became established the fashion of the vegetation changed, and the way was clear for the development of the still richer flora of the early days of the Carboniferous Period, which was destined to be surpassed in luxuriance and variety by the successive floras of the Coal Age.

Archæopteris is represented by numerous specimens of handsome,

bipinnate fronds bearing entire or deeply dissected cuneate leaflets. It is a remarkable fact that fronds of this genus from Ellesmere Land and Bear Island are at least as large as those obtained from the South of Ireland and other European localities.

We know more of Upper Devonian plants from the Northern Hemisphere than of those from the South; but there are no grounds for assuming any essential differences in the broader features of the vegetation throughout the Devono-Carboniferous world. The barrenness of the thick sedimentary series in South Africa below the oldest *Glossopteris* Beds and the Dwyka tillite precludes any accurate chronological estimate; but, if I may for a moment intrude into the domain of the Palæozoologist, the meagre evidence of fragmentary plants receives some confirmation from the remains of an Eurypterid. Dr. David White described some incomplete fossils from the coal-bearing rocks of Brazil under the generic name *Hastimima*: he suggested that they might be the remains of an animal, and applied to 'eminent American specialists in Vertebrate Palæontology', who were unwilling, however, to accept responsibility. Subsequently I recognized *Hastimima* in a collection of fossils from the Witteberg Series of Cape Colony and, believing it to be a segment of some Eurypterid, I submitted the material to the late Dr. Henry Woodward, who confirmed my guess and compared both the Brazilian and the African fossils with *Eurypterus hibernicus* from the Kiltorcan Grits of Ireland.

The occurrence of the relics of a luxuriant vegetation in the Upper Devonian rocks of the snow-covered cliffs of Bear Island, slightly south of lat. 75° N., merits especial attention. Oswald Heer, the pioneer historian of Arctic fossil floras, first recognized a close correspondence between the Bear Island plants and those from the South of Ireland. He assigned both floras to a position intermediate between the Devonian and Carboniferous Periods. Guided by a fuller knowledge, Prof. A. G. Nathorst classed both series of beds as Upper Devonian and made many additions to our knowledge of this Arctic flora. A few of the genera call for a passing notice: fronds of *Archæopteris* reach a length of 60 cm.; *Pseudobornia*, a genus in which are combined features shared by the later Calamites and the Sphenophylls, is represented by stout stems bearing whorls of fimbriate leaves; there are large dichotomously branched fronds of *Sphenopteridium Keilhaui*, recorded

also from Ellesmere Land, with feebly developed leaflets—fern-like in habit, though probably not a Fern. There were stems of no mean girth bearing broad decurrent leaf-bases, superficially at least resembling some of the Permo-Carboniferous Medulloseæ; the genus *Cephalopteris*, originally named *Cephalotheca*, founded on peculiar fertile fronds of doubtful affinity, was compared by Nathorst with existing Marattiaceous Ferns, though it is more probably a member of some wholly extinct group. It is convenient to include many of the Palæozoic fern-like fronds which cannot be assigned to a definite position under the non-committal name Pterophylls, a term originally proposed by R. Zeiller, and afterwards independently suggested by Nathorst. The venerable Lycopod phylum, which claimed attention last year, was prominent in the Bear Island vegetation; *Cyclostigma (Bothrodendron) kiltorkense*, a species founded on specimens from the Kiltorcan Series, is represented by a wealth of material, consisting for the most part of dichotomously branched stems and foliage-shoots with occasional *Stigmaria*-like rhizomes. Closely allied or possibly identical species occur in Upper Devonian beds of North America and Germany, and an imperfect specimen in the Jermyn Street Museum from the Marwood Beds near Ilfracombe may belong to the same genus. Stems of precisely similar habit, though difficult to determine with accuracy because of the bad state of preservation, are recorded from Devonian and Lower Carboniferous strata in South Africa and Australia.

The plant-beds of the more northerly Spitsbergen Archipelago, though exceptionally rich in the remains of a Lower Carboniferous flora, are poor in Upper Devonian species. One Spitsbergen plant, which has not been found in Bear Island, is *Psygmophyllum Williamsoni*, founded on a large wedge-shaped leaf with numerous spreading veins. The generic name *Psygmophyllum*, instituted for Permo-Carboniferous specimens, is applied to cuneate leaves, either entire or deeply lobed, usually much larger than the leaflets of *Archæopteris*, though in some forms there is little to choose between them, and agreeing in the shape of the lamina with the leaves of that 'living fossil' *Ginkgo biloba*. It is tempting to follow some authors who regard *Psygmophyllum* as a remote ancestor of the Maidenhair tree; but we have no knowledge of the botanical affinity of this ancient type, which was already in existence in the latter stage of the Middle Devonian Period. There is no justification for interpreting the partial similarity to *Ginkgo* as an indication of relationship.

From Ellesmere Land (approximately lat. 80° N.), Nathorst has described many exceptionally well-developed fronds of *Archæopteris*, also a few other Upper Devonian plants, including pieces of bark referred to the genus *Dictyodendron*, belonging to a tree about 2 feet in diameter, which I am inclined to think may be closely allied to the giant Lycopodiaceous trees described by Dr. J. M. Clarke from the Catskill Mountains. It is noteworthy that some of the Ellesmere Land *Archæopteris* fronds are specifically identical with forms from the Donetz Basin in Southern Russia, and the specimens from the high Arctic region are larger than those from the more southern locality.

Additions to our knowledge of the Upper Devonian flora of County Kilkenny and County Cork in Ireland have recently been made by Prof. T. Johnson of Dublin. A few Upper Devonian plants have been described by M. E. Bureau from the Loire Basin in France, including specimens which he refers to the Bear Island *Cephalopteris*. Many plants of the Bear Island flora are represented in Upper Devonian beds in Belgium, and it is a pleasure to note that Prof. A. Gilkinet of Liége has recently returned, after many years, to a field of work with which his name will always be associated. From Canada, the Eastern United States, and Germany records of a similar type of vegetation have been investigated by several palæobotanists. From English rocks only a few fragmentary remains have so far been recorded, some of which were described by the late Dr. E. A. Newell Arber. A specimen of *Archæopteris* from Berwickshire, now in the Edinburgh Museum, and figured long ago by Hugh Miller, is evidence of the existence of at least one of the later Devonian types in Southern Scotland.

Sir William Dawson, many years ago, described a petrified piece of stem from the Upper Devonian of the State of New York as *Asteropteris noveboracensis*, and Prof. Paul Bertrand of Lille subsequently published a full account of the type-specimen. *Asteropteris* is one of the oldest Ferns: the conducting tissue, as seen in transverse section, forms an irregular stellate cluster with widely spreading and slender arms radiating from the centre, a plan of construction more elaborate than might be expected in a primitive type. A similar arrangement of the vascular tissue occurs in the Permian *Asterochlæna* of Central Europe, a genus distinct from *Asteropteris* but a member of the same family, the Zygopterideæ. We know very little of the habit of the fronds.

Another member of the same unfamiliar family of Ferns, *Clepsydropsis*, was recorded a few years ago by Mrs. T. G. B. Osborn from New South Wales, and more recently Prof. Sahni has described a specimen, from a different locality in that State, which seems to belong to the same type: the age of the Australian rocks is either Upper Devonian or Lower Carboniferous. From Upper Devonian and Lower and Upper Carboniferous rocks many beautifully preserved pieces of stems and leaf-stalks, with occasional sporangia, have been described as relics of plants included in the Zygopterideæ, the extinct family of Ferns to which *Asteropteris* and *Clepsydropsis* are assigned. Unfortunately, though we know much of their anatomical structure, it has not been possible to connect any leaf-impressions with the stems and petioles. The Zygopterideæ are classed as Ferns: certain features in their anatomy and in such sporangia as are known suggest comparison with recent genera. There is, however, a wide gap between the oldest-known Ferns and those of the present day, also, one may add, between the great majority of Palæozoic Ferns and the essentially modern type which flourished through successive stages of the Mesozoic Era. Our knowledge of the older Palæozoic genera has in recent years been substantially increased by the researches of many palæobotanists, among whom I would mention Prof. Paul Bertrand and Prof. W. T. Gordon.

The occurrence of plants in the later Devonian floras, with arborescent stems resembling in the structure of their secondary wood Araucarian Conifers, is clearly established. A brief account of *Palæopitys Milleri*, of Middle Devonian age, has already been given: it is a species of obscure affinity, and in certain respects inferior in its construction to some more robust and highly organized Gymnosperms from both Middle and Upper Devonian localities. One of the oldest Gymnospermous stems of the higher type is *Callixylon Marshii*, described in 1922 by C. J. Hylander from the Middle Devonian rocks of the State of New York. From beds in Ohio, which are probably Upper Devonian in age, D. P. Penhallow described another species of the same genus, and Elkins & Wieland recorded an example of *Callixylon* from Upper Devonian strata of Indiana. M. D. Zalessky also described a species from the Donetz Basin of Russia. Though we know nothing of the foliage of these trees, our wonder is stimulated by the complexity of their anatomy and the astonishing similarity in structural details to

some living Conifers. The genus *Callixylon* is the oldest-known representative of the family Pityeæ, which includes genera possessing Araucarian features in the woody cylinder, associated with certain peculiar characters which distinguish them from all living Gymnosperms. The massive trunk of another genus (*Pitys*) of the Pityeæ is a conspicuous object in the grounds of the Natural History Museum at South Kensington. Such facts as are available point to a high level of vascular construction; a detailed comparison of the elements of the wood of these Devonian trees with those of recent Conifers reveals a wonderfully close correspondence, despite a separation in time amounting to several hundred million years.

As an example of another type of Upper Devonian woody stem, differing more widely in the complexity of its tissues from existing plants, reference may be made to the genus *Cladoxylon* from beds probably of Upper Devonian age in Thuringia, and recently recorded from Lower Carboniferous rocks in Scotland. This and other genera included in the family Cladoxyleæ have been compared both with Ferns and with Pteridosperms; they may, however, well be regarded as offshoots of a blindly ending line of evolution in which complexity outran efficiency. There were many plants in the Devono-Carboniferous floras exhibiting a wide range in stem-structure within the limits of a plan that was soon to be discarded; the diversity in detail may be regarded as attempts on the part of a short-lived race to superimpose upon an unsuitable primary structure the capacity to develop a continuously enlarging mass of secondary conducting tissue. Effort to convert a slender herbaceous stem into a woody column in which the girth is regularly increased is one of the tendencies of which recurrent manifestations are seen in many Palæozoic types.

Architecture has been defined as the art of building suitably with suitable material: the material used by plants became stereotyped in the earliest periods of which we have records that can be read; but it is the unconscious effort to use the material economically and efficiently of which we have many glimpses in the diversity of anatomical construction revealed by the older fossil plants. Some stems with a single axial strand of conducting tissue solved the problem of acquiring the habit of trees, while others failed to attain stability because of mechanical obstacles created by the addition of secondary wood to independent conducting strands that could not expand without mutual interference. It is by trial and error,

by the substitution of a relatively simple type of organization for the inconveniently complex that evolution has progressed. Reduction and simplification have played a much greater part than is generally admitted, and one of the impressions left after reviewing the late Palæozoic types is that many elaborately constructed plants which failed to attain the attributes that make for survival furnished, during their comparatively brief career, conspicuous examples of the capacity of plastic organs to vary within certain limits without being able to produce descendants endowed with the ability to persist. There were others in which progress was assured by the nature of the primary architectural scheme, and in these increase in size was compararatively easy and rapid. Their fate was not extinction, but reduction in size and the loss of the arborescent habit.

A comparison of Upper Devonian floras shows no indication of any botanical provinces or of differences in the vegetation of widely separated regions beyond differences that are relatively unimportant. The plants of Ellesmere Land and Bear Island were at least as vigorous as those of Central and Southern Europe. If we assume, as we seem compelled to assume, that the Earth's axis has not substantially altered its position since the Palæozoic Era, we must remember that in the Devonian Period, as to-day, the Arctic vegetation endured a long annual interval of quiescence. Have we any reason for supposing that the close resemblance between the plants of Ellesmere Land and Bear Island on the one hand, and those of the same age in North America, the South of Ireland, Belgium, Germany, and the Donetz Basin of Southern Russia on the other hand, is inconsistent with the assumption that in polar regions the vegetation experienced an alternation of continuous sunshine and a prolonged sunless period; while that of more southern latitudes flourished under conditions comparable with those prevalent in Central Europe to-day?

Our present standards are chiefly based on a comparative study of the Flowering Plants: it is on them that we see most distinctly the impress of external factors. The prostrate Willows and the trailing stems of the dwarf Birch on the slopes of the Greenland plateau bear eloquent testimony to the stress of circumstances: in habit, in girth, and in structure they offer a striking contrast to their Devonian predecessors with which, despite the absence of direct relationship, they may be compared ecologically. It is

conceivable that on a large continental area of comparatively low elevation the vegetation on the polar edge would not differ sufficiently from that in the southern regions of the same continent to enable us to detect in the form and fashion of the waifs and strays of the forests characters attributable to the influence of an Arctic climate. A long winter's rest is in itself not an insuperable difficulty: more open communication by currents between the polar land and warmer seas in the south, the absence of the withering winds which, by robbing a plant of water when the low temperature of the soil puts the roots out of action, would, it may be suggested, be sufficient to produce the required transformation.

It has often been asserted that the presence of red rocks in the continental Devonian areas is evidence of an arid climate. The late Prof. J. Barrell pointed out that red muds are carried by the waters of the Amazon and Congo which flow through tropical forests; he maintained that the Upper Devonian plants do not indicate arid conditions, but a climate in which seasonal rainfall alternated with partial aridity. Such morphological facts as we have do not warrant the assumption of desert conditions. We have practically no knowledge of the anatomical characters of Arctic Devonian plants, but in the wood of some of those from temperate regions there are well-developed rings of growth. It is hardly conceivable that the Upper Devonian plants lived under arid conditions; in the short Arctic summer we may assume rapid and concentrated growth, while farther south the growing period was more prolonged, but the hours of work shorter. The wide dispersal of some of the Upper Devonian plants is not difficult to understand when we note the wealth of spore-bearing organs on the fronds of *Archæopteris* and other genera; but it is impossible as yet to follow, with any degree of confidence, the wanderings of the early terrestrial types from one hemisphere to the other. We know that some members of the Northern flora existed in the remote South, and the balance of evidence favours the view that the continent of Atlantis was the chief centre of dispersal.

The Earlier Carboniferous Floras.

When he reaches the chapter of geological history that is written in the coal-seams and associated muds and sands of the Carboniferous swamps and estuaries, and in the earlier plant-bearing strata of the same Period, the Palæobotanist offers his services with greater confidence to the Stratigraphical Geologist. The records of plant-

life rapidly increase as we pass from the Upper Devonian rocks to the Coal Measures. I am not now concerned with the Algæ of the Carboniferous seas which, as Prof. E. J. Garwood's researches demonstrate, possess a high value as zone-indicators. Some years ago Dr. R. Kidston expressed the opinion that, in Carboniferous rocks where they occur in sufficient quantity, plants 'give the surest test of age'. Species pass from one horizon to another; but, as the same author says, if 'in forming our opinion of the age of rocks from the fossil plants they contain, we take a view of their floras as a whole, errors arising from false values being placed upon individual species are entirely eliminated'. Last year Dr. Kidston recurred to the same subject in the first part of the Memoir on the Fossil Plants of the Carboniferous Rocks of Great Britain, a Memoir which calls for an expression of deep gratitude both to the Director of the Geological Survey and to the author:

'It is no longer necessary' [he writes] 'to defend the employment of fossil plants as a means of zoning or dividing the Carboniferous formation into smaller Groups or Series, as these fossils are now universally recognized as affording the most certain data for zoning this formation, both on the continent of Europe and in America.'

The subdivision of the Carboniferous System and the floristic characters of the various series does not at the moment concern us: it is the broader botanical aspect that we are considering. While certain genera and even species are common to the Lower and the Upper Carboniferous strata, the floras of these two divisions of the system differ widely one from the other. The differences are, however, such as might be expected to accompany progressive evolution and a changing physical environment. On the one hand the number of species is smaller, though additions are constantly being made, and on the other there is a remarkable assemblage of types at the height of their vigour. In North Staffordshire, Dr. Kidston reminds us:

'Upper Carboniferous plants are found in the so-called Millstone Grit rocks at a depth of about 50 feet below the Fifth Grit'; then succeeds a distance of about 60 feet of barren rock, 'when suddenly a typical Lower Carboniferous flora appears. The sudden disappearance of one flora and the equally sudden appearance of another is,' he adds, 'one of the most remarkable facts in vegetable palæontology, and one for which I can offer no satisfactory explanation.'

The most famous locality in Great Britain for Lower Carboniferous plants is Pettycur, near Burntisland, on the northern shore of the Firth of Forth. Although for the greater part small in

size, the fragments of stems, leaves, seeds, and spores scattered through calcareous volcanic ash are preserved in extraordinary perfection. Overwhelmed by volcanic eruptions, the disrupted tissues were permeated by solutions derived from the destroying material which converted the delicate membranes of the cells into an indestructible network of stone. The thoroughness with which it is possible to investigate the anatomy of vegetative organs and reproductive shoots reduces to insignificance the æons that have passed since the plant-machines throbbed with life. There are many differences between the grosser anatomical features of the Lower Carboniferous species and those of existing plants, but in the form and structure of the units that make up the intricate mechanism there is an impressive correspondence. The processes by which the raw materials were absorbed from the soil and the air and converted into the living protoplasm must have been the same then as now. As we examine the petrified tissues under the objective of a microscope they become endowed with life: we may apply to the trees of old the poet Gray's reference to trees of the present :

> 'While visions, as poetic eyes avow,
> Cling to each leaf and swarm on every bough.'

One almost sees the sun's rays entrapped by the chlorophyll of the cells, and the entrance through the countless pores in the leaves of the air which supplies the carbon for the food and substance of the plant. Ignorant as we are of the methods of Evolution we are convinced of the continuity through the ages of the finely adjusted relationship of the living machine to the world in which it lives.

In the time at my disposal it is impossible to convey an adequate idea of the many divergent types that have been described from Pettycur and other localities in Scotland. Several Devonian genera persisted, and produced additional forms; and it is rather the greater wealth of material than any marked change in plan that distinguished the phase of evolution which we are now considering. There are rhizomes and leaf-stalks of several new members of that extinct group of Ferns, the Cœnopterideæ (Primofilices of Arber) to which reference has already been made in the brief description of certain members of the family Zygopterideæ; stems of Pteridosperms that cannot be closely linked with those of any known plant; the seed-bearing strobilus *Lepidocarpon*, a type of fertile shoot that demonstrates the existence of a higher level of organization than is shown in any subsequent representative of the great

Lycopod group. Another remarkable spore-bearing cone is that described by Dr. D. H. Scott as *Cheirostrobus pettycurensis*, and spoken of as 'perhaps the most complex Cryptogamic fructification at present known to us': in it are combined features suggesting affinity both to the Calamites and to the Sphenophylls. In further illustration of the similarity of Lower Carboniferous types in widely separated regions, reference may be made to an account by Dr. D. H. Scott & Prof. E. C. Jeffrey of petrified stems and leaf-stalks from Lower Carboniferous rocks of Kentucky, which show a striking similarity in anatomical characters to species from Thuringia and other European districts.

Anatomically, the plant-world of early Carboniferous days presents to modern eyes a series of experiments in construction, temporary and unsuccessful attempts to harmonize complexity of structure with physiological efficiency. The arborescent habit of the Lepidodendra, the range in structure of the vascular axis from a small, solid strand of conducting tissue to a relatively large pith-enclosing tube encased in a broadening cylinder of secondary wood, the production of large cones of the type illustrated by the famous *Lepidostrobus Brownii* (admirably described in one of the later contributions by the late Prof. R. Zeiller to the science which he adorned), are examples of some of the many attributes and accomplishments of the Lycopod phylum which have long been lost. In the latter part of the Carboniferous Period *Lepidodendron* flourished from Australia to Spitsbergen and the North of Greenland; from South America to China. The discovery of a petrified stem of *Lepidodendron* in Lower Carboniferous rocks of New South Wales several years ago (though unfortunately the specimen has not been described), which agrees closely with European species, shows that similarity in structure as in habit of growth characterized the widely scattered members of the Lower Carboniferous floras.

One of the most characteristic and cosmopolitan plants of the period which we are now considering is *Asterocalamites scrobiculatus*, a species differing in certain well-defined characters from the Calamites of the Coal forests, but closely related to them. R. Kidston & W. J. Jongmans, in their valuable Monograph of the Calamarieæ, call attention to the occurrence in the older Carboniferous floras of a few species of *Calamites* intermediate between *Asterocalamites* and the later species of *Calamites*. *Asterocalamites* is recorded from the Far North, from North

America, through Europe, from South America and Australia. Among other genera characteristic of Lower Carboniferous rocks are several Pterophylls, fronds which are probably not those of true Ferns: such as *Cardiopteris* with broad oval leaflets. *Rhacopteris*, species of *Sphenopteris*, and several others, in addition to numerous genera founded on petrified pieces of stems and petioles with affinities to Gymnosperms and Ferns.

One of the outstanding features of the Lower Carboniferous vegetation is the occurrence of the same genera or even species in widely separated regions of the world. There are differences between floras which may be correlated with difference in geological horizon, and certain types are confined to single localities; but we have no evidence of any well-marked botanical provinces distinguished by such floristic characters as can be correlated with contrasted climatic conditions. Far within the Arctic Circle Lower Carboniferous plants flourished apparently with a vigour equal to that shown by those of much more southern floras. Closely allied and, often, identical species range from lat. 80° N. through Europe and North America, and are found also in the remoter parts of the Southern Hemisphere. Dr. John Ball, of the Egyptian Geological Survey, discovered specimens of *Lepidodendron* 15 miles west of the Gulf of Suez, in lat. 29° N., closely allied to well-known European species; and in 1922 Dr. J. A. Douglas submitted to me a small collection of plants from Peru which suggest comparison with Lower Carboniferous European species, although the American palæobotanist Mr. E. W. Berry has assigned specimens from the same region to an Upper Carboniferous position. In passing, it may be stated that plants from the Hartz Mountains referred by the late Dr. H. Potonié to a Silurian age are now generally accepted as typical examples of a Lower Carboniferous flora.

In 1911 Nathorst published a description of a few plants from a locality between lat. 80° and 81° N., on the eastern coast of Greenland. Nine species were recognized, including *Calymmatotheca bifida*, a British species of Pteridosperm that is recorded also from Spitsbergen and Bear Island, a species of *Sphenophyllum* closely allied to a Pennsylvanian and European form, specimens of *Asterocalamites*, a species of *Lepidodendron* which occurs in Spitsbergen and is hardly distinguishable from others recorded from Europe and the Southern Hemisphere, also specimens of

Stigmaria ficoides. The luxuriance of the Upper Devonian flora of Bear Island had its counterpart in the rich vegetation discovered in the Lower Carboniferous beds of Spitsbergen. A few characteristic Lower Carboniferous plants are recorded also from Bear Island. Thick seams of coal occur in Spitsbergen (lat. 78° N.), and at several localities the strata have yielded abundant casts and impressions of a large variety of plants. No undoubted Lower Carboniferous petrifactions are known from Spitsbergen: the species *Dadoxylon spetsbergense* described by W. Gothan as Carboniferous was not found *in situ*, and is said by Nathorst to have come from some marine deposit into which it may have been transported from a more southern home. This species has often been quoted because of the absence of rings of growth in the secondary wood—an unexpected feature if the tree had grown where it was found. The examination of sections of the type-specimen in Dr. Kidston's collection leads me to suspect that it may be of Mesozoic age. In any case, the species is untrustworthy as evidence of climatic conditions in the Arctic regions.

While in the possession of certain genera in common the Upper Devonian flora of Bear Island and the Lower Carboniferous flora of Spitsbergen resemble one another, the latter indicates progress in the range of plant-form. The Spitsbergen flora is rich in fronds which in habit agree closely with those of some Ferns, but not one of them can be assigned with certainty to the Filicineæ. Some of the axes have a breadth of 9 cm., and Nathorst's illustrations show pieces of fern-like rachises provided with recurved hooks with which they presumably clung for support to the branches of stouter trees. Species of *Sphenopteris* and other genera bearing small, deeply-cut leaflets present a striking similarity to British and Continental forms. The Pteridosperms also include the European *Calymmatotheca bifida*, and to the same class may be assigned *Adiantites bellidulus* with small cuneate segments recalling those of fronds from much more southern countries.

The Lepidodendreæ played a leading part in the Spitsbergen flora, and some of the species appear to be identical with representatives in Europe and even in the Southern Hemisphere. Among other species are *Lepidophloios scoticus*, a Lower Carboniferous Scottish form; a species of *Archæosigillaria* very similar to examples of the genus from the North of England and North America; and stems of *Porodendron* possibly identical with *Porodendron tenerrimum* (formerly known as *Bothrodendron*

tenerrimum), which occurs in abundance in the Paper-Coal of Russia.

The genus *Sigillaria*, one of the common trees of the Coal forests, played a subordinate part in the earlier Carboniferous floras. In addition to some reproductive organs connected or associated with Pteridosperm fronds, different types of highly organized seeds of unknown parentage have been found in the Spitsbergen beds. It is interesting to have evidence of the ability of Arctic plants to bring to maturity seeds which in size and complexity of structure show no signs of adverse climatic conditions. Mention may be made of seeds as large as hazel-nuts and very similar to Lower Carboniferous species from Belgium and Northern Russia: there are seeds provided with flanges, long and narrow seeds, with a slender beak covered with stiff hairs, resembling the fruits of the recent Stork's-bill. These and other examples demonstrate the existence of many types of seed-bearing plants, and show that, even in early Carboniferous days, plants had reached the stage of producing seeds equipped with appendages comparable with those which facilitate the dispersal of recent fruits and seeds.

There can be no question of the Spitsbergen plants having been drifted from a distance: stumps of trees occur *in situ*, and the state of preservation of the impressions clearly points to an autochthonous flora. Nathorst suggested the possibility that some of the seeds may have been borne by herbaceous plants; he assumed that the large fronds and the woody stems of Pteridosperms and Lepidodendra are descendants of herbaceous ancestors. The first land-flora he believed to have been herbaceous. There is no reason to suppose that in the earlier stage of evolution of the vegetation of the land herbaceous plants were abundant. The opinion of some botanists is that herbaceous plants are descended from arborescent parents, an opinion which receives considerable support from the records of the rocks. It is highly probable that a mixed vegetation would be represented in the geological series by a misleading proportion of woody forms, because of their greater resisting power to the wear and tear accompanying sedimentation; but, in the remains of the Palæozoic and of the earlier Mesozoic floras, we find comparatively few examples of typical herbaceous plants, and it is not unreasonable to infer from this and other facts that the present wealth of herbs is an especial feature of the later stages of evolution.

Upper Carboniferous Floras.

The vegetation that has left its traces in the sediments of the Coal Measures of the Northern Hemisphere and, in some few localities, is preserved in amazing perfection in calcareous nodules embedded in coal, is of exceptional interest—not only to the botanist, but to all to whom the wonders of Nature make an appeal. In a single Address concerned with a succession of floras it is clearly impossible to do justice to the mass of knowledge that has been accumulated: it is possible only to refer to a few of the many problems presented by a general consideration of Upper Carboniferous floras.

Lack of precise information is responsible for the common practice of applying the term Permo-Carboniferous to certain series of strata in the Southern Hemisphere and in India, instead of attempting a closer correlation of the Carboniferous and Permian rocks in different regions of the world. We cannot always distinguish between the two periods, even in the Northern Hemisphere; and, in some circumstances, it is preferable to retain the dual designation to which certain geologists have raised objections. On the other hand, we should not rest content with a terminology which tends to minimize the importance of recognizing, within as narrow limits as possible, the equivalents in the Southern Hemisphere of the productive Coal Measures north of the Equator. My intention is not to repeat in detail a story which was first clearly presented in a masterly Address to the British Association in 1884 by W. T. Blanford; it is rather to call attention to some of the contributions to knowledge in recent years which have influenced opinion on the relation to one another of the Northern and Southern Upper Carboniferous floras in their botanical and geological aspects.

A luxuriant and, in the main, a homogeneous vegetation clothed widely extended regions of the great Northern continent during the latest, prolonged phase of the Carboniferous Period: to the north it probably reached as far as Melville Island and Banks Land—but Arctic records are few and fragmentary, and it has been traced to Northern Africa on the southern shore of the Tethys sea. Many northern types have been found in the vast coalfields of China; but of the Far Eastern floras we shall have a much more accurate knowledge when Prof. T. G. Halle's researches are published. Among the records from the plant-bearing strata of India, Australia, South Africa, and South America we seek in vain

for many of the familiar northern plants. Gondwanaland supported a comparatively meagre flora, in which *Gangamopteris* and *Glossopteris* were dominant members. In 1914 it was my privilege to describe the fossil plants obtained by members of Capt. Scott's Second Expedition, whose heroism and tragic death are still fresh in our memories. The specimens of *Glossopteris* were collected from a nunatak on the Buckley Glacier in lat. 85° S. To the descriptive part of the account was added a brief summary of the botanical features of the two provinces which are usually spoken of as Permo-Carboniferous. It is unnecessary to traverse the same ground again; but, during the last ten years, some progress has been made, and there are still many questions that can only be answered in part. I ought to add that the age of the Beacon Sandstone in which the Antarctic *Glossopteris* fragments were found cannot be definitely fixed: the genus has a wide geological range, and there is no doubt that in the Beacon Sandstone are included beds belonging to more than one period.

We will first glance at the Northern flora, and then compare it with the floras preserved in the plant-beds of Gondwanaland, paying especial attention to considerations that may help us to arrive at a true conception of the homotaxial relations between the two, the possible effect of physiographical conditions upon the facies and composition of the floras, and, incidentally, referring to some of the more recent contributions to our knowledge of this much discussed and attractive chapter of geological history.

Many attempts have been made to construct restorations of the forests of the latter days of the Carboniferous Period, to call back to life the trees and humbler members of the undergrowth, and to picture the environment in which they wrought into their tissues the raw material from air and soil. Imaginary landscapes often fall short of realism, and depict such trees as never grew—they are

> 'Creatures borrowed and again conveyed
> From book to book—the shadows of a shade'—;

but they serve a useful purpose and remind us of the fact that the fossils which we name and describe were once parts of complex living organisms. The difficulty of accurately defining the climatic conditions necessary for the full development of members of the more recent floras, which are hardly distinguishable from existing species, becomes infinitely greater when we are concerned with associations in which the present dominant class of Flowering Plants is unrepresented. On the other hand, the plastic organs of

trees and herbs reflect in the plan of their construction, and in certain structural details, something of the environment in which they lived. The resistance of tall stems and flat, strap-like leaves to bending and tearing by the wind is registered in the disposition of the girders and cylinders of fibrous cells; the relation of the tissue-systems of roots, stems, and leaves to water-supply is within certain limits revealed on microscopical examination; the alternation of regularly recurring periods of rest and active growth associated with Temperate and Arctic regions, or it may be the succession of wet and dry seasons under the Tropics, is in some degree reflected in the annular distribution of wider and narrower conducting elements in the wood. The value of rings of growth as criteria of seasonal rhythm has, I venture to think, been overestimated: this opinion has also been expressed by Dr. E. Antevs, who has made the most exhaustive study of the subject of annual rings in recent and fossil plants that has been published. The science of Ecology, the study of plants in relation to their dwelling-places, is still in its youth: the comparatively little knowledge which has been gained by researches into the interrelation of living plants and the inorganic world should help us to resist the temptation of describing, with a confidence that is born of repetition, the precise circumstances in which the rich legacy of the productive Coal Measures was extracted from the atmosphere. It has been maintained that the extensive deposits of peaty material point to a cool rather than a tropical climate: on the other hand, attention has been called to the occasional accumulation of masses of vegetable débris in islands of the Malay Archipelago. Plants bearing needle-like leaves occur in the Coal Measures, also others characterized by fronds comparable in size with those of many tropical ferns. The bifurcate aërial stem of *Lepidodendron*, the more *Cactus*-like columnar *Sigillaria*,—both, it would seem, given off from Stigmarian axes spreading horizontally in the mud for many feet and, like the underground stems of recent dwellers in fens which are compelled by lack of a sufficient supply of oxygen in the deeper water-logged soil to grow near the surface,—afford evidence of a watery habitat. Similarly, the lacunar cortex of the roots of *Calamites* and some other genera is consistent with swamp conditions. There are certain anatomical characteristics exhibited by the vegetative organs of Upper Carboniferous plants suggestive of xerophilous attributes: a device for preventing excessive loss of water is illustrated by the stomatal grooves on the lower surface

of the leaves of *Lepidodendron* and *Sigillaria*; the occurrence in several plants of woody elements of a type which, in recent species, serve as water-reservoirs may be an indication either of scarcity of water or, more probably, of growth in a situation that was physiologically dry, as in a brackish or marine lagoon.

F. C. Grand'Eury's investigations in the coal-basins of France illustrate the value of patient field-work in palæobotanical research. Some of us have given much too little heed to the investigations of plants in relation to the sediments in which they occur. I am convinced that it is only by a combination of work in the laboratory and direct observation in the field that we can hope to obtain a true picture of the Carboniferous vegetation.

It is not unreasonable to conclude from the available data that the majority of the Northern Hemisphere plants inhabited swampy districts, either slightly below sea-level or exposed to occasional flooding by sea-water. We have no means of discovering whether, as is often asserted, the supply of carbon-dioxide gas in the atmosphere was greater than it is now; nor are there adequate grounds for assuming that the trees grew under a perpetual pall of mist:

> 'How can the tree but waste and wither away
> That hath not sometime comfort of the sun?'

The general absence of well-defined rings of growth of stems from the Coal Measures would seem to favour the conclusion that there were no sharply contrasted seasons; but we know too little either of the mechanism of secondary increase in girth in some of the Palæozoic trees, or of the relation between habitat and growth-rings in recent plants, to attach much weight to this kind of evidence. It may, at least, be said that there is no indication in the wood of the Upper Carboniferous trees of the Northern flora of regularly recurring diminution in the volume of the water-current, alternating with a sudden increase in the supply demanded by the burst of activity which we associate with the Spring awakening. We may as well admit that we have no trustworthy data on which to base a statement that the forests of the Northern Hemisphere grew under tropical conditions: circumstances were unquestionably favourable, but I suspect that one reason for the supposition of a tropical climate is that certain extinct genera attained the dimensions of trees, whereas their nearest living relations are low-growing and relatively inconspicuous plants. Differences in size and complexity of organization are rather the

expression of stages in evolution, and of the relation of one group of plants that was temporarily dominant to others which subsequently assumed a corresponding position at a later epoch.

A section of a calcareous nodule from a coal-seam reveals a miscellaneous collection of vegetable débris; fragments of woody stems, pieces of bark, leaves, an occasional seed, or sporangium filled with spores, burrowing roots invading foreign tissues that lie in their path, and threads of fungi penetrating the food-containing cells of higher plants. In a few localities, both in England and in Bohemia, attention has been drawn to the occurrence of certain plants in the coal, while others of a different type are confined to nodules in the roof of the seam: a sorting of species which may denote a differentiation between dwellers in swamps and dwellers on drier ground. With lower plants I do not propose to deal, beyond remarking that there are grounds for believing that the group Bryophyta was already in existence in the Coal Period.

The widely-distributed tropical Lycopod, *Lycopodium cernuum*, in habit like a diminutive tree, affords a fairly accurate representation of a much reduced *Lepidodendron*: the slender stems and branches of the living species were replaced by a tapered woody trunk bearing bifurcate lateral branches clothed with needle-like leaves, and from some of the shoots hung large pendulous cones. Spirally-disposed fleshy leaf-cushions covered the surface of the stem, except in the older portions, where they were replaced by an irregularly fissured bark. On the stems of some of the *Lepidodendreæ* cup-shaped scars similar to those on the trunk of a Kauri Pine showed that branches had been shed by a natural process of abscission. There is also the closely allied *Sigillaria*, plumed in the younger part with crowded awl-like leaves, but elsewhere showing vertical rows of contiguous, spiral series of leaf-scars; while nearer the base the original surface-features were obscured by the stretching and consequent sloughing process caused by long-continued growth in diameter. Below the surface of the swamp forked Stigmarias pushed their way, like snakes, through the spongy mud, their slender rootlets dispensing with the aid of absorbing hairs and thus foreshadowing recent water-plants. The great Lycopod group had reached the culminating point in its long career; from the older Devonian prototypes, themselves dwellers in peat, had been developed a vigorous race, many of them trees, some smaller and herbaceous: and a few had solved the problem

of seed-production by a modification of the normal method of reproduction by spores.

If we imagine a giant *Equisetum* converted into a taller woody column encircled at intervals by whorls of shoots with rings of star-like leaves or, nearer the ground, by series of descending spongy roots; and if, for the comparatively small and uniform type of spore-bearing strobilus, we substitute large cones of greater complexity and variety, we obtain a fairly accurate picture of the familiar *Calamites*.

The slender stem of *Sphenophyllum*, a genus already represented in Upper Devonian and Lower Carboniferous floras, must have presented a close resemblance to the scrambling stems of the common *Galium aparine* of our hedgerows. It is interesting to note that the large size of the tracheids in *Sphenophyllum* stems is a feature suggestive of a scrambling or climbing habit.

It is now generally agreed that the great majority of fern-like fronds from Carboniferous rocks were not, as they were naturally supposed to be, the foliage of Palæozoic representatives of recent Ferns. Many of them bore seeds, and the stems grew in thickness by means of a cambial cylinder. The combination in these extinct Pteridosperms of characters now shared by Ferns and Cycads seemed to indicate a common origin for the two groups; but the view now adopted by Dr. Scott, a view with which I agree, is that the Pteridosperms and Ferns probably represent different lines of evolution. The Pteridosperms afford one of several illustrations of the rise to prominence in the latter part of the Palæozoic Era of groups which are almost or entirely absent from Mesozoic floras. In the course of evolution similar morphological tendencies or similar types of construction, such as the production of seeds, the conversion of herbaceous into arborescent stems, were independently achieved along separate lines of progress, and are best interpreted as parallel developments rather than as symbols of relationship.

Tree-Ferns were also represented: some, like *Psaronius*, recalling recent Ferns in habit, and exhibiting in their anatomical characters a foreshadowing of later types of structure, though hardly entitled to be assigned to any Mesozoic or modern family. It is, I think, true to say that the Fern flora of the Coal Period is still very imperfectly known, and we have as yet no definite evidence of a direct connexion between the Palæozoic and the Mesozoic representatives of the Filicinean alliance.

The Gymnosperms played a prominent part in the Upper Carboniferous forests. It is impossible to draw a clearly-defined line between some of the plants classed as Pteridosperms and those which show a close approach in the anatomy of the stems to Cycads and Conifers. There is a continuity in the history of some of the extinct genera of Gymnosperms from the Devonian to the Permian Period: certain types agree in the structure of the secondary wood with Cycads and Araucarian Conifers, and it is noteworthy that several of the beautifully preserved seeds from the late Carboniferous rocks exhibit a striking agreement with those of recent Cycads. But the reproductive shoots which bore seeds exhibiting Cycadean characters were far removed from the typical seed-bearing cones that were subsequently evolved.

A bewildering variety of stem-structure becomes apparent when we examine the records from Upper Carboniferous strata: some forms show a vascular construction of a type now associated with lianes; but for the greater part one prefers to see in the range of anatomical plan unsuccessful attempts to solve the problem of an efficient water-supply, and the mechanics of growth in girth and resistance to the force of the wind. In the diversity of stem-structure, in the extraordinary complexity of seeds, in the unfamiliar habit of certain Palæozoic Ferns, and in many other morphological features, we have abundant evidence that the forests of the Coal Period included many plants of a type that is now unknown; some families were on the verge of extinction, others persisted in humbler guise, their later representatives being reduced both in size and in complexity of structure. As one group ceased to be prominent in the plant-world, another took its place; the dominant group of one age may not have any direct affinity to that which it in part replaces. Through a series of shifting scenes we can trace a few continuous lines of development, for a time broad and prolific in the production of new types; at a later stage less plastic, and overshadowed by newer products of evolution better attuned to an altered environment.

This brief sketch must suffice, though it affords a very inadequate presentation of the richness and variety of the vegetation which colonized vast areas in the Northern Hemisphere during the protracted phase of geological history that is written in the Upper Carboniferous rocks.

I have already pointed out that the sundering Tethys Sea did

not constitute the southern boundary of the Northern botanical province: members of the Westphalian flora have been recorded from Morocco. In 1883 Zeiller described the occurrence of several European species of Upper Carboniferous plants in the Tete Basin of the Zambezi district, a circumstance which seemed to demonstrate a distant migration of some northern elements towards the south; but in 1914 Dr. W. Gothan described several well-preserved specimens of *Glossopteris* leaves from the same district, and expressed the opinion that the specimens sent to Paris for description were of European origin. It has been proved that *Glossopteris* grew in the Zambezi district, and that the plants described by Zeiller from the same region did not include any representatives of the *Glossopteris* flora. There must have been some mistake: the conclusion seems to be inevitable that the northern vegetation did not, as was formerly supposed, extend into the African tropics.[1]

From several localities on the continent of Angara, one of the land-masses undisturbed by crustal convulsions and marine transgressions which Suess described as a refuge during a long succession of ages for terrestrial life, fossil plants have been recorded from beds referred to the Permian Period. Since Amalitzky's discovery of *Gangamopteris* and *Glossopteris* in Upper Permian deposits in Northern Russia, many additions have been made to our knowledge of the later Palæozoic Russian and Siberian floras, and I would especially mention the recent publication of a large Atlas of Fossil Plants from the older Angara Series of plant-bearing strata prepared by Prof. M. D. Zalessky, who promises a volume of descriptive text which will be a valuable supplement to the useful set of papers contributed by him to Russian journals. The older Angara floras, which are believed to be of Permian age, are connected by many common types with those of Western Europe and North America, but they also include representatives of the *Glossopteris* Flora. The Tethys Sea was, in the East as in the West, no impassable barrier to plant-migration: there is evidence of interchange between the two provinces. Lack of time precludes a full discussion of the Angaraland floras: an important point is that they are regarded by palæobotanists familiar with them as Permian and in part, at least, of Upper Permian age.

[1] I may remind geologists interested in palæobotanical research of the excellent résumé of literature by the Abbé Carpentier, published in the 'Revue Générale de Botanique'.

I pass now to the territories occupied by the *Glossopteris*, or, as Dr. White prefers to call it, *Gangamopteris* Flora in its most characteristic development. The composition of this southern flora need not detain us: E. A. Newell Arber's useful volume, published as a British Museum Catalogue in 1905, includes descriptions of the several species recorded at that time. *Gangamopteris* and *Glossopteris* are the two most familiar genera, but it is not always easy to draw a satisfactory line between them; though their affinities are still an open question, the balance of evidence is on the side of relationship with the Pteridosperms and not with the true Ferns. The most recent contribution to this subject is a paper published in our Journal by Dr. A. B. Walkom (whose revision of the fossil floras of Australia is providing a much surer basis for palæobotanical generalizations than has hitherto been available), wherein he presents evidence, which, though not actually proving that certain seeds and *Glossopteris* fronds found in close association were borne by the same plant, greatly strengthens previously formed suspicions. The researches of R. Zeiller and my predecessor in this chair, who has contributed not a little to our more accurate knowledge of the Indian Gondwana Beds, led them to regard the axes known as *Vertebraria* as the rhizome of *Glossopteris*. We are, however, still ignorant of the anatomical characters of *Vertebraria*. One of the widely distributed species in the southern floras is that generally called *Næggerathiopsis Hislopi*, a species represented by large, broadly linear leaves which I believe to be generically identical with those from several northern localities that are included in the genus *Cordaites*. Zalessky has described many leaves from the older floras of Angaraland which he identifies with the southern species. In the bed of the Vaal River in South Africa large tree-stumps have been found closely resembling those of the European *Cordaites*, and petrified wood exhibiting the characters of Cordaitean stems is not uncommon in the Southern Hemisphere. A recent revision of Indian specimens by Prof. B. Sahni and myself has supplied additional evidence in support of the union of *Næggerathiopsis* and *Cordaites*. Among the many important contributions which we owe to Mr. T. N. Leslie, of Vereeniging, may be mentioned the discovery of several species of *Lepidodendron*, a species of *Psygmophyllum*, and seeds recalling certain Northern Hemisphere types. From New South Wales foliage-shoots indistinguishable from those of *Annularia*, a common genus in North America and Europe, have been described by

R. Etheridge & A. B. Walkom. The Fern *Psaronius*, previously mentioned as a member of the Northern floras, was discovered many years ago in Brazil and, more recently, described in detail by the late Count H. Solms-Laubach. Whorls of wedge-shaped leaves on a slender axis, originally made the type of a new genus *Trizygia*, and long known from Lower Gondwana rocks in India, have more recently been found in Northern Australia and South Africa; as Zeiller maintained, there would seem to be no adequate reason for separating *Trizygia* from *Sphenophyllum*. The genus *Neuropteridium*, founded on pieces of pinnate, fern-like fronds characterized by large, lobed leaflets, is a far-distributed plant in the Southern Province; though recalling some Carboniferous European types, it is distinguished by certain, possibly unimportant, differences. *Neuropteridium*, in company with the genus *Schizoneura*, another common member of the Gondwana floras, occurs in the Lower Triassic flora of the Vosges district. In South America as in South Africa, members of the *Glossopteris* Flora grew side by side with Lepidodendroid species that are at least closely allied to common Upper Carboniferous and Lower Permian types from the north. Certain genera, such as *Lepidodendron*, *Sigillaria*, *Psygmophyllum*, *Cordaites*, *Psaronius*, *Sphenophyllum*, some Sphenopteroid fronds, and a few other plants are common to both botanical provinces. Others, such as *Gangamopteris* and *Glossopteris*, are absent from the Upper Carboniferous floras of the Northern Hemisphere, though they had reached the North of Russia before the close of the Permian Period; and *Glossopteris* persisted into Triassic time in Mexico and Tongking. *Glossopteris* flourished on Antarctica 300 miles from the Pole, but we cannot definitely fix the date of the rocks in which it was discovered. A piece of petrified wood, obtained by Mr. Raymond Priestley from a moraine on the glacier which bears his name in lat. 74° S., was referred by me to a new genus *Antarcticoxylon*; but, in the light of more recently acquired information from other sources, it has been recognized as a stem of the South African genus *Rhexoxylon*. Dr. Nellie Bancroft founded the genus *Rhexoxylon* on a piece of petrified stem, of uncertain age, sent to me by Dr. A. W. Rogers from Cape Colony. More recently, several additional and larger specimens were collected from Triassic beds in Rhodesia, and handed to me by Mr. H. B. Maufe. Dr. A. L. Du Toit also obtained specimens from the Beaufort Series, and these were generously passed on by

Dr. R. Kidston to Mr. John Walton, who described all the new material in an exceptionally interesting paper published last year. Originally believed to be a member of the Medullosear, *Rhexoxylon* has now been shown by Mr. Walton to be a distinct type, resembling in some anatomical features Southern Hemisphere species included in the genus *Dadoxylon*. *Rhexoxylon* was a widely distributed plant in Gondwanaland during the Triassic Period, and, incidentally, it may be added that some of the Rhodesian examples are among the most impressive relics of petrified stems that have ever been found. In its complex anatomical structure, which exhibits a striking resemblance to that of certain recent Dicotyledonous lianes, it affords a remarkable illustration of parallel development: in the breaking up of the secondary wood into wedge-shaped masses by the disruptive effect of actively growing softer tissue, it foreshadows a type of structure which, after the lapse of geological ages, was acquired independently by the stems of tropical climbers.

To turn now to the question of age. It is usual to include the oldest *Glossopteris* beds of Gondwanaland in the Permian System; or rather, it is truer to say that until recently this was the common practice. In a long paper published in Spanish in the Bulletin of the Cordoba Academy, Dr. J. Keidel follows the majority of authors in assigning the oldest *Glossopteris* beds and the tillites to a Permian age. The same conclusion is reached by J. C. Branner in his important contribution to the Geological Society of America on the Geology of Brazil. On the other hand, Dr. A. L. Du Toit, Mr. G. de P. Cotter, and Prof. B. Sahni have accepted the view, which I venture to think is the correct view, that the strata in question belong to the Carboniferous System. My contention is that the lowest beds containing remains of the *Glossopteris* Flora are, in all probability, homotaxial with the Upper Carboniferous rocks of the Northern Hemisphere. For some of the arguments on which this opinion is based I am indebted to Dr. Du Toit. Geologists are agreed that the spread of the *Glossopteris* Flora followed, or may even have been contemporaneous with, the formation of enormous glacial deposits over a very large area of Gondwanaland. The ice-scratched boulders from South America, the Falkland Islands, South Africa, India, and Australia, and the grooved and polished platforms of solid rock, prove beyond doubt the long-continued and far-reaching effects of thick sheets of ice

and, in some localities, of stranding icebergs. As Prof. W. M. Davis wrote: the glacial origin of the Dwyka Conglomerate is

'as unquestionable as is that of the drift-sheets of North-Eastern America and of North-Western Europe.'

Dr. Du Toit considers that, at the period of maximum glaciation, the ice in South Africa formed a continuous body across the African continent

'fully 1000 miles from east to west, and perhaps but little less than that from north to south.'

In Australia tillites have been recorded from 23° lat. S. in the west, 20° lat. S. in Queensland, and from as far south as 43° lat. S. in Tasmania. In India boulder-beds occur between 20° and 33° lat. N.; in South America from the Tropic of Capricorn to the Falkland Islands. As Prof. A. Penck says, in certain regions of Gondwanaland thick glacial beds are found where to-day the snow-line recedes to its maximum height.

Some of the Gondwanaland tillites have revealed traces of seasonal banding comparable to those discovered by Prof. G. J. de Geer in the Pleistocene deposits of Northern Europe and by Mr. R. W. Sayles in the Permo-Carboniferous tillites of Massachusetts, the exact age of which seems to be in doubt. Mr. T. N. Leslie recently found well-preserved impressions of *Glossopteris* leaves in pockets of shale, in depressions on dolomitic rocks overlain by the Dwyka tillite: an important piece of evidence in favour of the co-existence of *Glossopteris* and extensive glaciers. The late Sir Henry Hayden expressed the opinion that certain *Gangamopteris* beds in Kashmir are not younger than Upper Carboniferous. With the leaves of *Gangamopteris* were found impressions of *Psygmophyllum*. In 1922 Mr. Henry Woods announced the occurrence in the Upper Dwyka Shales of Kimberley of the Crustacean genus *Pygocephalus*, which had previously been found only in the Coal Measures of Great Britain and North America.

There is still much work to be done, and one of many desiderata is the discovery of trustworthy standards by which more accurately to correlate the rocks and their plant-remains in different regions of the Southern Continent. In this connexion I would refer to Dr. Du Toit's statement that the Iraty Shales of Brazil are the equivalents of the White Band of the Dwyka Series in South

Africa: the two stages are clearly connected lithologically, and contain closely allied Reptilian remains. Meanwhile the opinion may be offered that the present tendency is in favour of Du Toit's view that the southern ice-sheet should be assigned to the latter days of the Carboniferous Period.

When the Carboniferous floras reached their maximum development on the Northern Continent, the contemporary vegetation of Gondwanaland bore a different aspect; it was not wholly distinct, but included a few common types adapted to climatic conditions very different from those of the forest-clad swamps north of the Equator. Beyond the evidence of well-defined rings of growth in many stems from the Southern Province, we have practically no trustworthy criteria in the relics of the Gondwana floras from which to reconstruct the physical environment. Assuming that the oldest beds in India (as in other parts of the Southern Province) which contain remains of the *Glossopteris* Flora are of Upper Carboniferous age, and that those in which a few members of the same flora occur in Russia and Siberia are of Permian, and probably Upper Permian, age, it is reasonable to regard the Southern Continent as the original home from which the long northward journey began. The occurrence of Carboniferous glacial beds as far north as the Belgian Congo and in Northern India and the diversity in the direction of ice-movement in different regions raise difficulties which it is not easy to meet; but one thing at least is certain, the proposed shifting of the poles as shown in a map published by E. Koken some years ago does not provide a solution. Although it would be presumption on my part to attempt to discuss the possibility of finding assistance in our endeavour to recreate Gondwanaland in the much discussed hypothesis of Wegener, I must confess some sympathy with Dr. Du Toit's acceptance of the view that the present South America, South Africa, India, and Australia

'represent portions of the ancient continent finally torn apart, subsequently modified in outline by erosion, deposition, etc., and now separated by vast stretches of ocean.'

Post-Carboniferous Floras.

Between the vegetation of the Coal Measures and that of the earlier part of the Permian Period the differences are comparatively slight: there was no fundamental change; species and genera disappear, new forms are introduced, but there is as yet no clear

indication of the almost complete transformation of the plant-world which is apparent in the floras of the latest phase of the Triassic Period. One of the critical stages in evolution occurred in the interval between the late Permian floras and those which have left abundant traces in Keuper and Rhætic strata. The paucity of fossil plants in Lower Triassic rocks is well known. The occurrence of thick deposits of salt, the weathered surfaces of the Archæan rocks of Charnwood Forest, which, as Prof. W. W. Watts has told us, retain after numberless years the surface-features impressed upon them by blasts of desert-sand, enable us to reconstruct the background of one of the scenes of a drama which is still in progress. Connecting-links between the older and the newer floras are few and mostly unconvincing. As I have elsewhere said, the threads of life seem to have almost snapped, and one wonders whence came the new arrivals which, to our restricted vision, appear as aliens rather than the direct descendants of Palæozoic types. Whether the apparently sudden change in the face of the vegetation that is indicated by an analysis of Upper Triassic and Rhætic floras is attributable to the imperfection of the Record, or whether it may be interpreted as the manifestation of a new development from ancestral lines unconnected with those which can be traced through successive stages of the Palæozoic Era, we cannot definitely assert. We may be led astray by a too rigid faith in the doctrine of continuity. Is it not legitimate to assume that the process of unfolding began at different times and in different places? Continuity is an established fact; but there is evidence also of discontinuity; the dominant plants of one age may be regarded as the end-series of a long course of evolution without connexion with the lines along which another set of types reached a dominant position in an earlier age. The idea of the initiation of a new creation at more than one stage of geological history is not inconsistent with a belief in the essential principle of the doctrine of progress and regression. My point is that revolutions in the inorganic world—the prolonged accumulation of the materials of which continents are built, followed by crustal upheaval and the birth of mountain-ranges—had their counterpart in the living world. Some chains of life were destroyed; a few persisted in an attenuated form, still producing an occasional new link, while from time to time fresh chains were forged.

These speculations, based on meagre evidence, are of little value. As Dr. D. H. Scott has said,

'In our complete ignorance of evolution, we cannot hope for any definite success in tracing its course.'

Speculation, however vague, may stimulate discussion and serve as an incentive to a more thorough search for records in rocks belonging to the period which seems to be characterized by the apparently sudden transformation of one order into another.

The plant-bearing series of India and other parts of Gondwanaland and a detailed comparison of their contents with the successive floras preserved in that other great refuge of terrestrial life, Northern Angaraland, offer a promising field of work. Loss of faith in the more orthodox conception of the process of evolution should encourage us to search more diligently for materials that may serve for new foundations of belief.

In conclusion, I propose to return to an aspect of Palæogeography to which attention has already been directed: namely, the occurrence within the Arctic Circle of a vegetation in striking contrast with that which occurs in the same regions now. Last year, it was my privilege to deliver the Hooker Lecture before the Linnean Society, and the opportunity was taken of discussing certain problems of geographical distribution, especially those suggested by the sharp contrasts in geographical range revealed by comparison of Mesozoic and Recent Ferns. Attention was also given to the difficulty of connecting the Palæozoic and later floras.

Considered broadly, Rhætic and Jurassic floras are very similar in composition, and on palæobotanical evidence it is not always easy to arrive at a precise estimate of horizon within these periods. One of the richest and best-known Rhætic floras is that from Southern Sweden, which has been thoroughly investigated by Nathorst and other Swedish palæobotanists. A few plants that are probably Rhætic in age have been collected in Spitsbergen. In 1891–92 Dr. N. Hartz of Copenhagen collected many plants on the south-eastern part of Jameson Land, on the eastern coast of Greenland, between lat. 70° and 71° N., and his well-illustrated account shows that the plants present a close resemblance to those from the South of Sweden. In 1900 Dr. Hartz obtained much additional material from the same district, and, in his short statement of results, reference is made to the discovery of the genus *Dictyophyllum*, a common Rhætic and Jurassic fern which had not been previously found there. Last year several cases of Dr. Hartz's fossils were, at his request, sent to me from the

Mineralogical Museum of Copenhagen. I take this opportunity of expressing gratitude to him for entrusting to me an interesting piece of work which circumstances prevented him from undertaking. It is as yet impossible to say much about the East Greenland flora beyond summarizing results already published: it includes Ferns, Cycads, and other Gymnosperms which show a very close resemblance, often amounting to specific identity, to forms from Scania, Franconia, Tongking, and other regions. There occur well-developed Equisetaceous stems, differing chiefly in their rather greater diameter from the Horsetails which grow in abundance to-day on many parts of the Greenland coast; large, bipinnate *Cladophlebis* fronds specifically identical with a widespread Rhætic fern; fertile leaves of *Todites*, a familiar Rhætic and Jurassic genus; large fan-like fronds of *Dictyophyllum* recalling those of a recent species of *Dipteris* which, often in company with *Gleichenia*, forms dense tangled brakes on the borders of the Malayan forests; twigs of Conifers; foliage-shoots of the cosmopolitan *Podozamites*; some Cycadean fronds, and other plants. We have seen that the Upper Devonian flora of Bear Island gives no sign of any response to conditions different from those under which the more southern floras existed; there is a corresponding similarity between the Rhætic Arctic flora and those preserved in what are now more favoured parts of the world. Similarly, an equally impressive example of contrasts between the Present and the Past is furnished by the Jurassic plants of Graham Land, first briefly described by Nathorst, and subsequently fully described and illustrated by Prof. T. G. Halle. This flora, which flourished close to the Antarctic Circle, a region that is now even more inhospitable to vegetation than are Arctic lands, includes several species identical with Upper Gondwana plants from India and with Jurassic forms from the Yorkshire coast. Some of the Graham Land plants are closely allied to species from Cretaceous rocks on the west coast of Greenland. To Prof. Halle we are also indebted for a description of an Upper Jurassic, or possibly a Wealden, flora from Patagonia including specimens of Ferns generically identical with *Gleichenia*, which has its greatest development in tropical and subtropical countries at the present day and is represented by several forms in the Cretaceous flora of Greenland. It is noteworthy that Upper Jurassic strata in Tierra del Fuego have furnished pieces of fronds of *Dictyozamites*, a Cycadean genus recorded also from Japan, India, England, Bornholm, and a few other parts of the world.

The discovery in recent years of numerous Jurassic plants, as also plants of other ages, in Alaska, the description of which we owe to Dr. F. H. Knowlton, affords additional evidence of the vigorous development of many southern types in high northern latitudes.

'In place of the present snow and ice' [writes Knowlton] 'and the scant, almost perpetually frozen soil which supports but a handful of depauperated plants, the conditions from at least late Paleozoic to middle Cenozoic time made an abundant and luxuriant vegetation possible, at least during certain periods.'

Two components of the Jurassic flora of Alaska may be mentioned: an Indian type of Cycadean frond and some exceptionally large leaves of a world-wide species of *Ginkgo*. From the far eastern border of the Northern Hemisphere Nathorst has recorded the occurrence in the New Siberian Islands of well-known Jurassic genera, and an Equisetaceous stem closely allied to Upper Triassic and Rhætic species in far distant parts of the world. A rich flora has been described by Nathorst from Spitsbergen which suggests near relationship to those of Wealden age in England and elsewhere. From Jurassic rocks in Franz Josef Land several species have been described both in our Journal, by Sir Jethro Teall & Mr. E. T. Newton, and by Nathorst in a contribution to the official Norwegian account of Dr. F. Nansen's voyage in the *Fram*.

Numerous Cretaceous plants were described by Oswald Heer about sixty years ago, and others have been added in more recent years by several authors, from Disko Island and the adjacent coast of Greenland at or about lat. 70° N. The plant-beds of Greenland, except in a very few localities where there is evidence of marine conditions, are entirely freshwater in origin, and contain no other fossils but plants. Heer's classification of these beds into the Kome, Atane, and Patoot Series has been generally adopted. In 1921 collections were made by Mr. R. E. Holttum and myself from Cretaceous and Tertiary deposits in Western Greenland, and I hope in the near future to give a general account of the older floras. It is doubtful whether Heer's threefold division rests upon a satisfactory basis: there are indications of a much more intimate connexion between the floras, which he assigns to different Cretaceous series, than Heer supposed. The most interesting feature botanically is the mixture of certain Ferns, species of *Ginkgo*, some Conifers,

and a few other plants, which appear to be indistinguishable from members of European and North American Wealden floras, with a considerable number of Dicotyledons. No Flowering Plants have been found among the many specimens collected from Wealden strata in England, and there is an almost complete absence of undoubted representatives of that class in all known Wealden floras. In the Cretaceous vegetation of Greenland Flowering Plants played a conspicuous part, and it is customary to assign the strata to a position considerably higher than the Wealden Series. It may be that within the Arctic Circle some of the older Cretaceous forms persisted longer than in more southern regions, and became the associates of species belonging to the present dominant class. It is often stated that Flowering Plants began their surprising career in the early days of the Cretaceous Period. They have not been found abundantly in rocks older than the Lower Cretaceous, but the Class is undoubtedly pre-Cretaceous in origin. Some years ago I described a leaf from the Stonesfield Slate which it is difficult to believe was not borne by some Dicotyledon. More convincing and much more important evidence was briefly outlined a few years ago by Mr. Hamshaw Thomas, based on examples of Angiospermous fruits enclosing seeds, discovered by him in the Jurassic rocks of Yorkshire. The full account of this new type is awaited with more than ordinary interest. The apparently sudden production and rapid spread of new forms of Vascular Cryptogams and Gymnosperms in the latter part of the Triassic Period inaugurated a distinct series of floras which, with frequent modifications, persisted to the end of the Wealden phase: the sudden rise to prominence of the Flowering Plants was the cause of a change in the balance of power in the plant-world, strictly comparable with that which occurred in the early days of the Mesozoic Era.

It is noteworthy that several Greenland and North American plants have been recently described by Dr. A. N. Krishtofovich from Cretaceous beds in the island of Sakhalin.

One of the most serious difficulties confronting the student of post-Wealden floras, in which Dicotyledons took a leading part, is the accurate determination of leaf-impressions usually unaccompanied by reproductive organs. Enthusiastic palæobotanists and others who, without much experience of recent plants, have endeavoured to interpret the botanical records, have often been led astray in their conclusions by the temptation to accept as evidence

of affinity characters that have little or no taxonomic value, and by neglecting the laborious duty of making as wide a comparison as possible between fossil and recent species. It has been demonstrated that even detached leaves, if the preservation is adequate, are well worthy of careful study. In this connexion an appreciative reference may be made to Miss H. Bandulska's recent descriptions of the leaf characters of some English Tertiary species of Dicotyledonous leaves. I am convinced that, if full advantage be taken of the experience and knowledge of botanists familiar with families of living Angiosperms, the rich material obtained from Cretaceous and Tertiary rocks is capable of yielding results of great importance.

Attention may be called to two of the many questions with which the student of the past history of Flowering Plants is concerned: (1) the wanderings of genera from one region to another, and (2) the evidence afforded by fossil Angiosperms of climatic change. The Arctic Cretaceous and Tertiary floras of Greenland and other northern lands need thorough revision and a more careful comparison than they have as yet received with floras that still exist. If we confine ourselves for the moment to a few among many trustworthy identifications by American and European palæobotanists, the question at once arises,—are we justified in assuming that the occurrence of a plant within the Arctic Circle generically identical with species now characteristic of the tropics implies a change comparable with that indicated by the geographical separation of the fossil from the existing species? Nathorst discovered leaves and flowers of an *Artocarpus* in the Cretaceous rocks of Disko Island, which are hardly distinguishable from those of the recent tropical Bread-fruit tree *Artocarpus incisa*, and in 1921 Mr. R. E. Holttum and I found fragments of the same genus at another Greenland locality. Of the Ferns that we collected about 300 miles north of the Arctic Circle the genus *Gleichenites* was by far the commonest: it is represented by specimens of dichotomously branched fronds practically identical in habit, in the structure of the sporangia, and in the arrangement of the vascular tissue in the leaf-stalks, with species of *Gleichenia* which are to-day the most familiar Ferns in the tropics.

With the Gleichenias and other genera, which recall tropical plants of recent floras, occur many Dicotyledons, some of which are also tropical; but others, especially the abundant leaves of a

Platanus, which are almost identical with those of the living Plane-tree, suggest temperate or south temperate conditions. One of the most persistent and far-travelled Gymnosperms in Jurassic, Cretaceous, and Tertiary floras is the genus *Ginkgo* or *Ginkgoites*. We collected many well-preserved leaves of this genus in the plant-beds of Upernivik Island a short distance north of lat. 71° N., which in the form of the lamina, in the venation, and in the structure of the epidermal cells and stomata, differ in no single feature that can be regarded as fundamental from the leaves of the Maidenhair tree. But what is the value of *Ginkgo* as a thermometer of past ages? The tree is believed to be extinct in an absolutely wild state: it doubtless survived in China, where indeed it may still be found beyond the limits of civilization, longer than in any other part of the world. To-day it grows freely, and occasionally flowers, in England as in more southern countries, readily adapting itself to a wide range of climatic conditions. The occurrence of the genus in Greenland, Spitsbergen, Franz Josef Land and in several other Arctic regions does not justify the assumption of a mean temperature higher than that of temperate latitudes at the present day. Another widespread Gymnosperm, characteristic of Tertiary strata, is *Sequoiites Langsdorfii* from Ellesmere Land in lat. 77° N.: Nathorst recorded the occurrence of numerous carbonized twigs, which can be picked out of the matrix like old herbarium specimens, practically identical with those of the Redwood that is now restricted to the Pacific border of California.

The knowledge that many recent plants can live and reproduce themselves in Arctic as in temperate lands, and our experience of the possibility of introducing tropical species to cooler regions, should warn us against hasty generalizations on the subject of fossil plants as tests of climate. It is in the highest degree probable that in the course of ages the constitution of a plant changes; its power of response may become impaired and operative within narrower limits. As Mr. C. E. P. Brooks has shown in his helpful book, 'The Evolution of Climate', it is possible to form a fairly accurate estimate of the effect produced by alteration in the distribution of land and water over the Earth's crust. Even assuming that the axis of the Earth may be moved without reversing the verdict of astronomers, no position of the Poles has been discovered which would solve the problem that we are considering. It is impossible to deal adequately with the subject of Palæoclimatology, on which there is a voluminous literature. The general

tendency of authors is, I think, to adopt too rigid an attitude towards plants as criteria of climatic changes.

I have endeavoured to show that palæobotanical evidence points to one conclusion: the Greenland ice-sheet is the expression of a comparatively recent phase of earth-history in sharp contrast to the more favourable climatic environment that is reflected in the procession of ancient floras. The vegetation which clothed the Arctic plains or relatively low hills in the ages that have passed was merely an extension of that which flourished in districts much farther south; it was not comparable in facies to the vegetation which in these abnormal, modern days has been compelled to assume a distinctive Arctic character.

The later stages of the history of the plant-world have in recent years received attention at the hands of many workers. I would refer especially to the admirable researches of Mrs. E. M. Reid and Miss M. E. J. Chandler in this country who, by adopting and extending the method of attack successfully employed by the late Mr. Clement Reid, have given us a clearer insight into the series of events chronicled in the scattered relics of Tertiary and post-Tertiary floras which preceded and immediately followed the latest Glacial Period.

After a long and rapid traverse from the first colonization of the land through the dim vistas which lie between, we reach the more familiar world of living plants. A retrospect into the remote past reveals many interruptions in the historical narrative, many missing pages in the most exciting parts; but, imperfect though it be, knowledge acquired by intercourse with the plants which were increases our respect for those which are. The tapestry of vegetation rejoices the hearts of us all; its beauty can be seen by unquestioning eyes; but I like to think that a desire to discover the methods by which it was fashioned quickens our imagination, and makes us more responsive to the Poet's fancy:

> 'The herded Pines commune, and have deep thoughts:
> A secret they assemble to discuss
> When the sun drops behind their trunks which glare
> Like grates of hell.'

The rocks give us the material for our work; but it is only close contact with the living world which makes us realize that the Past, the Present, and the Future, 'all are but parts of one stupendous whole'.

February 27th, 1924.

Prof. W. W. Watts, Sc.D., F.R.S., Vice-President, in the Chair.

Edward Patrick Corbett-Sullivan, 83 Queen's Gate, S.W. 7; David Hartley Foster, B.Sc., 5 Frederick Road, Wylde Green, Birmingham; Mabel Elizabeth Tomlinson, B.A., M.Sc., Polesworth, Tamworth (Staffordshire); and Howel Williams, B.A., M.Sc., 188 High Park Street, Liverpool, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'Age and Origin of the Lough Neagh Clays.' By William Bourke Wright, B.A., F.G.S.

March 12th, 1924.

Prof. W. W. Watts, Sc.D., F.R.S., Vice-President, in the Chair.

Douglas Wallace Bishopp, A.R.S.M., Mazapil Copper Company, Aranzazu, Concepcion del Oro, Zacatecas (Mexico); William Ion Collins, B.Sc., 18 High Street, Northfleet (Kent); and Harold William Cornes, B.Sc., 25 Macdonald Road, Friern Barnet, N. 11, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Descriptions of Gasteropoda, chiefly in the late Mrs. Robert Gray's Collection, from the Ordovician and Lower Silurian of Girvan.' By Jane Longstaff (*née* Donald), F.L.S., F.G.S.

2. 'The Old Red Sandstone of the Cardiff District.' By Albert Heard, M.Sc., F.G.S., and Richard Davies, M.Sc.

Specimens of Ordovician and Lower Silurian Gasteropoda were exhibited by H.M. Geological Survey and by the Geological Department of the British Museum (Natural History), on behalf of Mrs. Jane Longstaff.

March 26th, 1924.

Dr. J. W. Evans, C.B.E., F.R.S., President,
in the Chair.

Agnes Elizabeth Bamber, M.Sc., 14 Watkin Terrace, Northampton; Leonard Charles Coe, B.Sc., Ringwood, Kingsland Road, Worthing; John Hancock, B.Sc., Lane Ends, Sandwell Street, Walsall (Staffordshire); and Gordon Murray Stockley, A.R.C.S., A.I.C., Geological Survey, c/o Public Works Office, Kingston, Jamaica (B.W.I.), were elected Fellows of the Society.

The List of Donations to the Library was read.

The President announced that the Proceeds of the Daniel-Pidgeon Fund for 1924 had been awarded to Kenneth Stuart Sandford, B.A., D.Ph., F.G.S., University College, Oxford, who proposes to investigate the Pleistocene Geology of the Thames Basin, west of Goring Gap.

The following communications were read:—

1. 'The Fossil Elephants of the Upper Thames Basin.' By Kenneth Stuart Sandford, B.A., D.Ph., F.G.S.

2. 'Some Upper Viséan Corals of the Genus *Caninia*. By Herbert Price Lewis, B.A., F.G.S.

Drawings, etc. by the late Dr. John McCulloch, F.R.S. (President of the Geological Society, 1816–1818), and books from his Library, presented to the Society by Miss E. Estridge, were exhibited.

Specimens of the teeth of Fossil Elephants from the Upper Thames Basin were exhibited by Dr. K. S. Sandford; and specimens of Upper Viséan Corals of the Genus *Caninia* were exhibited by Mr. H. P. Lewis, in illustration of their respective papers.

April 9th, 1924.

Dr. J. W. Evans, C.B.E., F.R.S., President,
in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'The Volcanic Series of Roch, Trefgarn, and Ambleston (Pembrokeshire).' By Herbert Henry Thomas, M.A., Sc.D., F.G.S., and Prof. Arthur Hubert Cox, D.Sc., Ph.D., F.G.S.

2. 'On an Olivine-Rhyolite in the Tertiary Volcanic Series of Eastern Iceland.' By Leonard Hawkes, M.Sc., F.G.S.

The President showed the Morte Slate fossils from Barricane Beach described by himself and Mr. R. W. Pocock some years ago, and presented to the Geological Survey. He had since had the opportunity of comparing them with those figured by the late Dr. Henry Hicks, and now preserved in the Sedgwick Museum at Cambridge. He was satisfied that the *Spirifer* was in both cases *verneuili* and that the age of the beds was Upper Devonian. The good preservation of one example was due to a local arenaceous facies of the rock which did not take the cleavage.

A specimen of 'cone-in-cone' structure from the South Wales Coal Measures, Waencoed Colliery, near Newport (Mon.), was exhibited by the Rt. Hon. the Lord Boston, F.G.S.

Specimens of volcanic rocks from Pembrokeshire were exhibited by Dr. H. H. Thomas & Prof. A. H. Cox, in illustration of their paper; and specimens from the olivine-rhyolite flow of Eastern Iceland were exhibited by Mr. L. Hawkes, in illustration of his paper.

May 7th, 1924.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Eric J. Bradshaw, B.A., B.A.I.(Dublin), Assistant Superintendent, Geological Survey of India, Calcutta; John Reginald Jones, B.A., 300 Newport Road, Cardiff; and Maurice Plevins Latter, B.A., Weald Place, Sevenoaks (Kent), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'The Silurian Rocks of the Clwydian Range, from Moel Arthur to Gyrn.' By Mrs. Ethel Gertrude Woods, D.Sc., F.G.S., and Miss Margaret Chorley Crosfield, F.G.S.

Specimens of Silurian rocks and fossils from the Clwydian Range were exhibited by Mrs. E. G. Woods & Miss M. C. Crosfield, in illustration of their paper.

May 21st, 1924.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Lawrence Fayrer Arnold Edgell, B.A., Beckley Rectory (Sussex), was elected a Fellow of the Society.

The List of Donations to the Library was read.

Mr. Carl Adolph Sussmilch, F.G.S., delivered a lecture on the Geological History of South-Eastern Australia, with special reference to the Carboniferous and Permian Periods. The Lecturer pointed out that rocks of definite Archæozoic age occur only over a limited area in the western part of the State; they contain the important silver–lead–zinc ore-deposits of the Broken Hill District. Proterozoic strata are limited also to the same area; these contain glacial tillites which have usually in the past been considered Cambrian, but they are probably of pre-Cambrian age. No undoubted Cambrian strata are known to occur in New South Wales.

Ordovician strata are very extensively developed, both in New South Wales and in Victoria: they consist mainly of claystones with some fine-grained sandstones, and contain an abundant graptolite-fauna. Both Lower and Upper Ordovician strata are found in Victoria, but so far only the latter have been identified in New South Wales.

Silurian strata are developed over extensive areas in New South Wales, particularly in the southern and central parts of the State, and extend also through the centre of Victoria; in addition to claystones, there is a considerable development of limestones, individual beds ranging up to 550 feet in thickness. An abundant coralline fauna is preserved in these limestones, and there are also many brachiopods and hydrozoa.

The sea appears to have retreated from the land at the close of the Silurian Period in South-Eastern Australia, but renewed transgressions of limited extent took place early in the Devonian Period. The sedimentation which took place in these areas in Lower and Middle Devonian times was accompanied by very extensive deposition of lavas and tuffs, this being one of the important volcanic epochs of South-Eastern Australia. Thick coralline limestones were also deposited during that age. Important crustal movements took place at the close of Middle Devonian

times, followed by an extensive transgression of the sea in New South Wales in the Upper Devonian Period, a transgression which extended from the present south-eastern coast almost to the far western boundaries of the State. In the strata deposited in this epicontinental sea an abundant brachiopod fauna is preserved, as also numerous fish-remains. Important crustal movements took place at the end of the Devonian Period, which brought about a complete withdrawal of the sea; much of South-Eastern Australia has not since been beneath the sea.

Early in the Carboniferous Period a geosyncline developed in North-Eastern New South Wales, and in this was first deposited a series of marine strata in the latter part of Lower Carboniferous times. Following a withdrawal of the sea, an extensive series of terrestrial beds was deposited in this area in Middle and Upper Carboniferous times; these terrestrial strata consist mainly of conglomerates, volcanic rocks (lavas and tuffs), and glacial beds, of an aggregate thickness approaching 10,000 feet. The glacial beds are of such a thickness and volume as to imply intense and long-continued glaciation. Associated with these deposits is a characteristic *Rhacopteris* fossil flora.

In Permian (Permo-Carboniferous) time an alternating series of marine and freshwater beds was deposited in the north-eastern part of New South Wales, and these extend far northwards into Eastern Queensland. The freshwater beds contain the most productive coal-measures of Australia, and associated with the coal-seams is the characteristic *Glossopteris* flora. The glacial conditions of the Carboniferous Period continued also far into the Permian Period, but with apparently reduced intensity. The Permian Period closed in North-Eastern New South Wales and South-Eastern Queensland with pronounced orogenic movements, accompanied by granitic intrusions; but elsewhere in New South Wales, and throughout Victoria and Tasmania, no earth-folding took place at that time.

In the Trias-Jura Period the whole of Eastern Australia stood above the sea, and extended far east of the present shore-line. Upon this land there developed a number of large lake-basins, in which several thousands of feet of freshwater strata were deposited; and in some areas productive coal-measures were formed.

In the Cretaceous Period a transgression of the sea began in the north, and extended southwards over Central Queensland into Northern New South Wales, and well into Central Australia. At the beginning of the Tertiary Era a tilting of the Australian continent on an east-and-west axis caused the Cretaceous sea to retreat northwards, and allowed of transgression taking place over considerable areas in the south, incidentally separating Tasmania from the mainland.

The close of the Tertiary Era was marked by a great epeirogenic uplift in Eastern Australia, which produced the existing tablelands that trend parallel to the eastern coast of Australia. The elevation of these tablelands was accompanied by extensive block-

faulting. During the Pleistocene Period limited high areas in New South Wales and Tasmania supported glaciers and ice-sheets; more recently, a subsidence of the land (or raising of the sea-level) drowned the shore-line to an extent of about 200 feet, and still later an upward movement of the strand-line of some 10 to 20 feet has taken place.

A cordial vote of thanks was unanimously accorded to the Lecturer by the Fellows present.

Specimens of glacial conglomerate from Bacchus Marsh, and a specimen of *Fenestella* from the Permo-Carboniferous of Allandale, Maitland (N.S.W.), were exhibited by Mr. G. W. Lamplugh, F.R.S., F.G.S.

June 4th, 1924.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On a New Catopterid Fish from the Keuper of Nottingham.' By Prof. Henry Hurd Swinnerton, A.R.C.S., D.Sc., F.G.S.

2. 'A Preliminary Survey of Metamorphic Zones in the Southern Highlands of Scotland.' By Cecil Edgar Tilley, Ph.D., B.Sc., A.I.C., F.G.S.

June 25th, 1924.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Robert Ashley Baldry, B.A., Lobitos, Paita (Peru); James William Pardoe, A.K.C., Ivanhoe, Boundary Road, Wood Green, N. 22; and Donald Parkinson, B.Sc., 61 West View, Clitheroe (Lancashire), were elected Fellows of the Society.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the non-payment of the arrears of their Annual Contributions.

The List of Donations to the Library was read.

The following communications were read :—

1. 'The River-Deposits of the Lower Valley of the Warwickshire Avon.' By Miss Mabel Elizabeth Tomlinson, B.A., M.Sc., F.G.S.; with an Appendix by Alfred Santer Kennard, A.L.S., F.G.S., & Bernard Barham Woodward, F.L.S., F.G.S.

2. 'On the Development of *Leptoplastus salteri* Callaway and other Trilobites (Olenidæ, Ptychoparidæ, Conocoryphidæ, Phacopidæ, and Mesonacidæ).' By Frank Raw, B.Sc., F.G.S.

Spherical flints and a bored stone from the river-terraces of the Avon valley were exhibited by Miss Tomlinson, in illustration of her paper; and an extensive series of lantern-slides was exhibited by Mr. Raw, in illustration of his paper.

THE

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FOR 1924.

1. *On* REPTILIAN REMAINS *from the* KARROO BEDS *of* EAST AFRICA. By SIDNEY HENRY HAUGHTON, B.A., D.Sc., F.G.S. (Read January 24th, 1923.)

[PLATES I & II.]

THE fossil remains described and discussed in this paper were taken from about the middle of the Karroo Beds near Tanga, on the coast of the Tanganyika Territory, by Mr. F. P. Mennell, F.G.S., who was good enough to forward the specimens to me for examination. They consist of portions of three animals, of which one is too weathered and too fragmentary for investigation. The other two are preserved on slabs of hard, blackish, somewhat micaceous shale; the more complete animal is smaller than the other, but, as will be seen in the sequel, in other respects they are sufficiently similar to be considered representatives of the same species.

It is not necessary to dwell on the importance of Mr. Mennell's discovery. From extra-South African areas very few of its animals have been found within the ancient boundaries of Gondwanaland: that some of them were spread outside its confines is well-known; but hitherto there has been a big geographical gap between the South African localities yielding a Gondwana fauna and those of Europe. This discovery marks the first step in the bridging of that gap; and I am extremely grateful to Mr. Mennell for giving me the opportunity of placing it on record.

Of the described specimens, the smaller and better is placed in the Rhodesian Museum, Bulawayo; the other is in the collection of the South African Museum at Cape Town.

Smaller Skeleton.

As preserved, the specimen has a length of about 380 mm. There are missing, however, the whole of the front third (at least) of the skull and a considerable portion of the tail. It is probable that the head, neck, and body had a combined length of about 23 cm., and that the tail—of which 165 mm. are seen—was considerably longer than the presacral portion.

The skeleton is crushed flat and displayed from the ventral side, a large number of the bones having been split horizontally in the splitting of the shale. From a point about 8 cm. behind the sacrum the tail has been twisted through a right angle, so that thence to the end of the slab it is seen in lateral view. The animal is wholly articulated. The fore-limbs are stretched backwards alongside the body; the hind-limbs are flexed at the knee—the femora standing out from the body, the lower portions of the legs pointing backwards parallel to the axis of the body.

Skull.—The portion of the skull that remains is preserved in palatal aspect, and the details of its structure are difficult of determination. In shape the skull was elongate and narrowly triangular, with a maximum breadth posteriorly of about 22 mm. and a probable length of between 50 and 60 mm., of which 38 mm. are present. No teeth are visible.

In the back part of the skull there is a triangular median area of bone, bounded laterally by curved swollen edges which seem to have a definite posterior end. Between the ends of these is possibly a transverse suture, separating the triangular plate from a small flat bone lying behind it. The triangular plate is continued forwards as a short median keel—formed by the union of the swollen lateral edges of the plate—on each side of which are small flat plates of bone. This region may be considered the base of the skull—the posterior bone being the basioccipital, and the other larger bone the basisphenoid, with definite flat basipterygoid processes.

The pterygoids seem to meet in the middle line, there being no interpterygoid vacuity. The posterior palatal vacuity is narrow, and not very long. The internal nares are not in the posterior half of the skull.

The whole of this interpretation is open to doubt, and no reliance is placed upon it in the subsequent consideration of the affinities of the animal.

Vertebrae.—It is highly probable that the vertebral column is notochordal.

The neck is short. The number of cervicals is doubtful, as they are largely obscured by the bones of the shoulder-girdle; but it was almost certainly not greater than seven.

There are apparently eighteen presacrals. The centrum of each is about 7 mm. long and 6 mm. broad at the ends. The posterior dorsals at least carry long transverse processes.

There are three sacral vertebræ fused together.

Twenty-four caudals are preserved. The first ten are cut through horizontally, and show short broad centra with long transverse processes. The remainder are twisted through a right angle, and have fairly high, long, flattened neural spines, distinct zygapophyses, and large chevrons, the distal half of each of which is expanded and laterally compressed. The posterior part of the preserved portion of the tail was obviously flattened from side to side in life, and was powerful. The chevrons of the anterior caudals, beginning at the third post-sacral vertebra, are small.

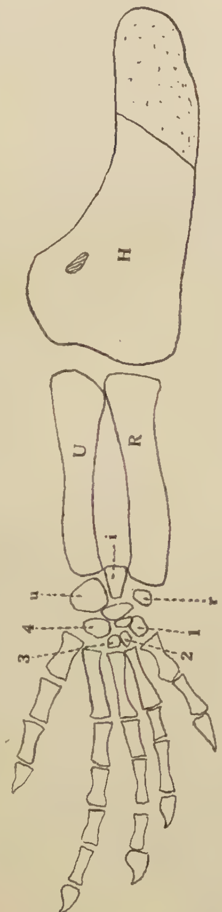


Fig. 1.—Tangasaurus mennelli *Haughton*. *Outline drawing of the ventral view of the left front limb of the smaller specimen. Natural size.*

[H = Humerus. U = Ulna. R = Radius. *i* = intermedium. *u* = (carpal) ulnare. *r* = (carpal) radiale. 1–4 = First to fourth carpals.]

Ribs.—The ribs are single-headed, fairly short, and not expanded distally. There are numerous fine abdominal ribs, which are not articulated and the true arrangement of which is not seen.

Shoulder-girdle.—The scapula is badly preserved, but was probably short. The coracoids are large, meeting one another in the middle line above the interclavicle. The coracoidal element is single. The posterior border just below the glenoid cavity is concave, and there is a coracoidal foramen approximately in the middle of the bone.

The clavicles are rib-like bones the ends of which are not seen. The interclavicle has a thin lanceolate median splint underlying the junction of the two coracoids, and passing back to the sternal plate. The sternum is 26 mm. long and 26 mm. broad, of a rounded shape, touching the coracoids anteriorly. Its border does not seem to be notched.

Fore-limb.—The humerus is 36 mm. long. It is an extremely massive bone, with a breadth of 17 mm. at the distal end. The proximal end is not entire, being split in a plane parallel to that of the distal end; but it was probably expanded in a direction at

right angles to this, and the whole bone was thus of a twisted form. The shaft is 9 mm. broad at the middle; below this it swells to the distal end, but the swelling takes place almost entirely on the ulnar side of the bone, the radial edge being nearly straight. There is a well-developed entepicondylar foramen.

The radius is 21·5 mm. long, about half a millimetre longer than the ulna. The ulna is a straight bone, the radius slightly doubly bent. The ends of each are but slightly swollen. The proximal end of the radius is simply convex; that of the ulna has its radial half obliquely convex, while its outer half is flatter and almost at right angles to the length of the bone. The distal end of each bone is cushioned.

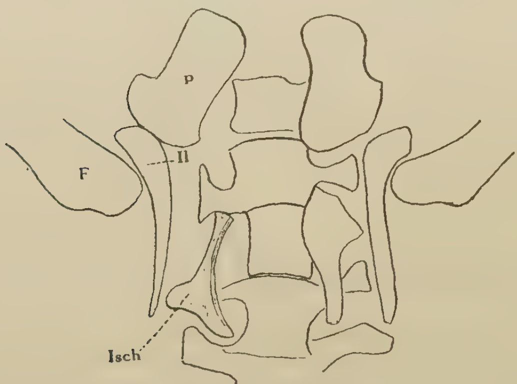
The carpus consists of ten bones. The proximal row is formed by the radiale, intermedium, and ulnare, of which the last is the biggest and the first the smallest. There are two centralia, one lying distal to the intermedium and also touching the ulnare; the other, and smaller, lying between the first centrale and the row of carpalia. There are four carpalia arranged in an arc, the fourth and first being larger than the others.

The digital formula is 23453.

Measurements in millimetres of the lengths of the metacarpals and phalanges are as follows:—

	I.	II.	III.	IV.	V.
Metacarpal	5	7	7·5	8	5
Phalanx 1	5	5·5	5	5	5
Phalanx 2	4	4·5	5·5	4	5·5
Phalanx 3	—	4	5	4·5	4
Phalanx 4	—	—	4	4	—
Phalanx 5	—	—	—	3·5	—
Totals	14	21	27	29	19·5

Fig. 2.—*Outline drawing of the sacral region of the smaller specimen: Natural size.*

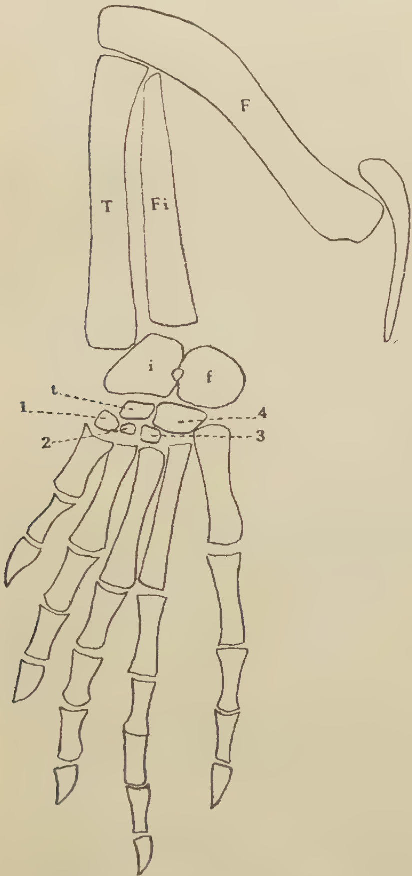


[F=Femur I=Ischium. Il=Ilium. *p*=pubis.]

Pelvis.—The ilium was at least 22 mm. long. Its shape is not discernible, but the post-acetabular portion is much longer than the pre-acetabular. The post-acetabular process was thin, while the bone was thicker in front.

The pubis is small—a slightly elongated plate-like bone expanded proximally. The greatest length is 15 mm., the proximal width 10·5 mm., and the distal width 7 mm. No pubic foramen can be seen.

Fig. 3.—*Outline drawing of the right hind limb (ventral view) of the smaller specimen. Natural size.*



[F=Femur. T=Tibia. Fi=Fibula. i=intermedium. f=fibulare. t=tibiale. 1–4=first to fourth tarsals.]

The ischium is not well enough displayed for description.

Hind-limb.—Compared with the massive humerus, the femur is a very slender bone, slightly **S**-shaped, showing no evidence of a trochanter on the shaft. Its length is 39 mm.

The tibia and fibula are long slender bones, very slightly swollen at the ends. The tibia is 34 mm. long, the fibula 31 mm.

The tarsus on each side is seen—the bones being mainly in section or occurring as moulds. In the proximal row there are two large bones, which meet in a long articulation broken in the middle by a small foramen, in the border of which each bone plays a part. The inner bone articulates with both tibia and fibula and is identified—following Broom's recent work on the Reptilian Tarsus—as the intermedium. The other has a rounded outer edge which stands out as a heel, and is the fibulare. Distal to the intermedium is a smaller bone, somewhat rhomboidal in outline, which articulates

with the 1st, 2nd, and 3rd tarsalia distally and with the 4th tarsal laterally. This is the tibiale. Of the tarsalia, the 4th is a large bone articulating with both the intermedium and fibulare, and supporting the 4th and 5th metatarsals; the 1st, 2nd, and 3rd are small, and each supports a metatarsal.

The digital formula is 23454.

The length in millimetres of the metatarsals and phalanges of the digits is as follows:—

	I.	II.	III.	IV.	V.
Metatarsal	8	14	17	17	14
Phalanx 1	6·5	6·5	7·5	10·5	11
Phalanx 2	5	6·5	6·5	7	7·5
Phalanx 3	—	5	6	6	6
Phalanx 4	—	—	5·5	5·5	4
Phalanx 5	—	—	—	5	—
Totals	19·5	32	42·5	51	42·5

The fifth toe is thus as long as—or perhaps slightly longer than—the third.

Larger Skeleton.

In the larger skeleton the vertebral column is disarticulated, except for a portion of the tail, and the isolated vertebræ are seen either in longitudinal or in transverse section. The head and neck are missing. Of the shoulder-girdle, the coracoids, interclavicle, and sternum are preserved. The limbs are present, but the bones of the feet are disarticulated. An ischium can be distinguished.

Vertebrae.—The mid-dorsal vertebræ are 8 mm. long and 15 mm. high. Each has a high long flat neural spine and a large neural canal. The notochord was persistent. The centra are slightly constricted in the middle. There are no intercentra.

A section through a sacral vertebra 15 mm. high shows a greatly reduced dorsal spine, a large neural canal, and transverse processes, 10 mm. long, on each side arising from the top of the centrum, and forming the sacral ribs.

The anterior caudals also have well-marked transverse processes. The mid-caudals have neural spines similar to those of the mid-dorsal region, and the chevrons here are large, with an expanded and flattened end.

Ribs.—The ribs are single-headed, fairly short, and not swollen distally.

Shoulder-girdle.—The shoulder-girdle is imperfectly preserved. The scapulæ are not present. The coracoids are large, and are so displaced that they do not meet in the middle line. The coracoidal border is notched behind the glenoid cavity, and there is a coracoidal foramen. In front of the coracoids are portions of

splint-like bones which must have been the clavicles. The interclavicle gives evidence of spreading anteriorly to form a bone with a rhomboidal head.

The sternum is large, its lateral edges being notched for the reception of sternal ribs. It is 30 mm. long, and as broad as it is long.

Fore-limb.—The humerus—preserved only in section—is massive and very similar to that of the smaller skeleton. It is 47 mm. long, the same length as the femur. It is strongly expanded distally, and has an entepicondylar foramen. As in the smaller specimen, the distal expansion is almost entirely due to the swelling of the ulnar side of the bone.

The radius and ulna call for no comment. The former is 28 mm., the latter 29 mm. long.

The carpus and hand are preserved; but the bones are all displaced from their true positions.

Pelvis.—An ischium is preserved, mainly as a mould. It is a plate-like bone, with a length of 19 mm. and a maximum breadth of 15·5 mm. Its outer edge is concave, the posterior edge straight. Its inner anterior corner is notched, indicating the presence in the complete pelvic basin of a small ischio-pubic vacuity.

The pubis is incomplete, but shows a well-marked pubic foramen near its posterior border.

Hind-limb.—The hind-limbs are strongly flexed at the knee, and the bones of the feet are separated one from the other; but it is possible to measure the various phalanges for purposes of comparison with the other specimen.

The femur is 47 mm. long, slightly sigmoidal in outline, with no separate capitulum but a pronounced step in the outline at the lesser trochanter. Its proximal width is 11 mm.; the distal end is well rounded in section. The minimum width of the shaft is 6 mm.

The tibia is 40 mm. long and slightly bowed. Its ends are not much expanded. The fibula is more slender than the tibia, and 37 mm. long. The bones of the tarsus are displaced.

The following table gives the lengths of the bones of the toes, measured in millimetres:—

	I.	II.	III.	IV.	V.
Metatarsal	8	15·5	18·5	20·5	16.5
Phalanx 1	7·5	7·5	9	10·5	12
Phalanx 2	7	7	7	7	8
Phalanx 3	—	5	7	7	7
Phalanx 4	—	—	5	6·5	5
Phalanx 5	—	—	—	5·5	—
Totals	22·5	35	46·5	57	48·5

Comparison of this table with that given for the pes of the smaller specimen shows that there is a general similarity, but

that in the larger specimen the 4th metatarsal is longer than the 3rd, whereas in the smaller specimen they are of equal length; also that the 5th toe is longer than the 3rd, instead of being equal to it. In both the 1st phalanx of the 5th toe is the largest in the foot. The 5th metatarsal is much broader proximally and of stouter build than the others, but has no Rhynchocephaloid development. The claw of the 1st toe is stronger than the others.

In neither skeleton is there any evidence of an armature of bony plates or ossicles. On the slab containing the smaller specimen, however, a few thin scale-like markings are preserved near the tail. The scales are elongate-rhomboidal in shape, and have a slight longitudinal median ridge. Each scale is 8 mm. long and 3 mm. broad; and the scales are so arranged that the free posterior borders of each overlap the anterior edges of the two lying directly behind it.

There can be little doubt that the two specimens are closely related, and indeed, despite slight differences in structure, they will be considered here as two individuals of the same species. The form is certainly undescribed, and it is proposed to name it *Tangasaurus mennelli* gen. et sp. nov. It remains to consider the relations of this new genus to other known forms, and to discuss the evidence which it affords as to the age of the deposits containing it.

In the absence of any exact knowledge of the structure of the skull, and especially of the nature of the temporal arches, it is impossible to define the position of *Tangasaurus* with any accuracy; but certain interesting comparisons can be made in considering the post-cranial skeleton, bearing in mind the fact that, as indicated by its general structure, the form is a partial adaptation to aquatic conditions.

Although *Tangasaurus* possesses certain primitive features, for instance, a plate-like pelvis, notochordal vertebræ, digital formulæ, it can readily be distinguished from the primitive types usually called Cotylosaurs and recently combined as a sub-class by Broom under Williston's name Anapsida; it is advanced in the direction of the Diapsida and Anomapsida, in that it has lost the anterior coracoidal element. The Anomapsida of Broom contain the Mesosauria, Sauropterygia, and a number of genera tentatively grouped by Prof. D. M. S. Watson in the order Protorosauria; and comparisons may first be drawn with some of these.

Mesosaurus is a form similarly adapted to aquatic conditions. Points of resemblance between the two are (1) probably elongate face; (2) form of vertebræ—expanded superiorly, perforated by notochord, amphicœlous, intercentra not present in the cervical and dorsal regions; (3) ribs single-headed; (4) coracoidal bone single; (5) pelvis plate-like, with obturator foramen; (6) long tail; and (7) the presence of abdominal ribs. These points of resemblance are either primitive features, or due to aquatic specialization; and

against them must be set a number of features in which *Tangasaurus* differs from the Upper Dwyka form. These are (1) short neck; (2) massive humerus, which is as long as the femur; (3) the presence of a large rounded sternum; (4) no distal swelling of the ribs; (5) neural spines of the tail and chevrons flatter and larger; (6) claws stronger; and (7) the presence of only four distal carpals and four distal tarsals. These features are of varying importance; but the possession of five carpalia and five tarsalia was the chief ordinal character assigned by Baur to his Proganosauria; and *Tangasaurus* cannot therefore be grouped in the order with *Mesosaurus*.

Protorosaurus is not completely known. It, too, has vertebræ with light neural arches, single-headed ribs, a large single coracoidal bone, and an interclavicle with an expanded anterior end; but the hind-limbs are considerably longer than the fore-limbs, and there is, apparently, no epicondylar foramen in the humerus.

Kadaliosaurus, to which *Aræoscelis* is said to be closely allied, has a persistent, very slightly constricted notochord, single-headed ribs, two sacral vertebræ, hind- and fore-limbs of equal length, a single coracoid, a plate-like pelvis, claws on the toes, and a strong armature of abdominal ribs as in the new genus. On the other hand, the dorsal vertebræ are long, the neck is long (*Aræoscelis*), there is an ectepicondylar foramen, and possibly an entepicondylar as well (*fide* Williston), and the structures of the carpus and tarsus are different so far as they are known.

Aphelosaurus differs in the slender humerus; but its dorsal vertebræ are short, without intercentra, the cervicals are short, the coracoids are large, single, and meet in the middle line.

Broomia has notochordal centra, but heavy neural arches; it has intercentra throughout the vertebral column; its ribs are single-headed and slender; there are probably abdominal ribs; the interclavicle has a rhomboidal head; the coracoidal bone is single, with a coracoid foramen; the pelvis is plate-like; the carpus is much more primitive than that of *Tangasaurus*, as is the tarsus.

This short review shows that *Tangasaurus* cannot be considered as definitely allied to any of these forms, although some of them bear a certain amount of superficial resemblance.

Among the Diapsida the only comparisons that can be usefully drawn are with the Eosuchidæ and *Palæohatteria*. The Eosuchidæ contain the primitive Thecodonts *Youngina* and '*Eosuchus*', which latter may be allied to *Heleosuchus*. For details of the fragmentary skeleton of *Youngina* I am indebted to Dr. R. Broom.

In *Youngina* the scapula is short and slender, and there is a single rounded coracoid, notched on its posterior border, with a coracoid foramen. There is a sternum composed of two separate plates, each lying behind a coracoid, and meeting in the middle. The humerus is twisted, with an expanded distal end and an entepicondylar foramen. The manus is unknown. The pubis is

plate-like, with a pubic foramen; and the pelvis of '*Eosuchus*' is of a plate-like type, with the bones fairly similar to those of this new form, so far as comparisons can be made. In '*Eosuchus*' the tibia is longer than the femur, which is sigmoidally bent and, according to F. von Huene, like that of *Protorosaurus*. The tarsus of *Youngina* is fully known, and agrees well with that of *Tangasaurus*, except for the presence of a 5th tarsale. In the latter form, however, there is a considerable gap between the fibulare and the 5th metatarsal, and it is quite possible that there was a cartilaginous 5th tarsale. In *Youngina*, as in *Tangasaurus*, the 5th metatarsal is unspecialized and longer than the 2nd; in '*Eosuchus*' the 5th metatarsal is short, and has a specialized development similar to that of the Rhynchocephalia; in *Heleosuchus* it is not specialized, but is much shorter than the 2nd metatarsal.

Palæohatteria has five tarsalia, and no tibiale in its tarsus; it has intercentra throughout its column; its single coracoid is rather small; it possesses no sternum. In other respects it shows points of similarity with *Tangasaurus*.

From the perusal of such a review one is driven, first, to the conclusion that, in the absence of a knowledge of such critical parts of the skeleton as the temporal region and the skull-basis, it is extremely unwise to draw definite conclusions as to the systematic position or affinities of a form; and, secondly, to the result that probably *Tangasaurus* is an aquatic adaptation of some early Diapsid such as *Youngina*, possessing an extremely powerful humerus, a large sternum, reduced carpus, reduced tarsus, elongate clawed toes and fingers, and a long powerful flattened tail.

It must not be overlooked that this new genus has several lizard-like characters.

Age of the Deposit.

The only record of fossils from the beds near Tanga is that made by W. Bornhardt who, in 1900, mentioned that in the lower part of the sequence he obtained plant-remains identified by Potonié as 'stems of *Ullmannia* (*Brachyphyllum* type)' and 'bracts of *Voltziopsis*', assigned by him to the 'Upper Gondwana' horizon. Bornhardt considered it hazardous to distinguish between the horizon of these beds and those of Nyasa and the Rufiji River, which contain *Glossopteris*, on the evidence afforded by the few plant-remains only.

Glossopteris is a long-lived genus; it ranges in South Africa from the Ecca Series up into the Molteno Beds. Mr. Mennell informs me that he obtained it from a horizon just above that which yielded the remains described in this paper.

If the supposed connexion of *Tangasaurus* with *Youngina* be justified, then we may consider the shales which contain it as approximately the equivalent of the Middle Beaufort Beds (*Lystrosaurus* Zone) of South Africa. *Youngina* is from the uppermost

S. H. H. photo.

TANGASAURUS MENNELLI gen. et sp. nov.

[Larger specimen, × $\frac{2}{5}$ of the natural size.]

zone of the Lower Beaufort Beds. The Thecodonts of the Upper Beaufort Beds, both the semiaquatic *Erythrosuchus* and the lightly-built *Euparkeria*, *Mesosuchus*, and *Howesia* are more advanced than *Tangasaurus* in the structure of the pelvis, to mention one point only. Further evidence is necessary before any certain correlation can be made between deposits in areas so remote one from the other; but it is improbable that there is any serious error in considering the Tanga deposits as of, at least partly, Middle Beaufort age.[1]

EXPLANATION OF PLATES I & II.

Plate I.

Tangasaurus mennelli gen. et sp. nov. Larger specimen. $\times \frac{2}{5}$.

Plate II.

Tangasaurus mennelli gen. et sp. nov. Smaller specimen. About a quarter of the natural size.

Discussion.

Prof. D. M. S. Watson thought that, judged solely from the photographs exhibited, the small reptile from Tanga was neither a Mesosaurian of Lower Permian or Carboniferous age, nor a Nothosaur of Middle Triassic date, but much more probably either (as the Author suggests) allied to *Euparkeria*, or to *Broomia* and the lizards. If its systematic position can be accurately determined, it should give good evidence of the age of the deposits in which it is found.

[1] Mr. Mennell has since informed me that the Karroo rocks in the locality are several thousand feet thick, and that the fossils came from the middle of the Middle or Black Shale Series of the System, as developed near Tanga, the said series being over 2000 feet thick. The observations on the age of the beds, as determined by *Tangasaurus* must, therefore, be taken to refer only to the strata in which the fossil occurs, and not as an expression of opinion concerning the entire System, or even of the Middle Series.

2. *Les* Gisements *de* Mammifères Paléocènes *de la* Belgique.

By Prof. Louis Dollo, Sc.D., For.Mem.G.S., and Prof. P. Teilhard de Chardin, D.Sc. (Read June 20th, 1923.)

Sommaire.

I. Introduction.

Nous avons, actuellement, quatre gisements de Mammifères paléocènes, en Belgique.

Ce sont, en les énumérant dans l'ordre de leur découverte :

1. Erquelinnes (Hainaut).[1]
2. Orsmael (Brabant).[2]
3. Leval (Hainaut).[3]
4. Vinalmont (Liége).[4]

L'un de ces gisements (Orsmael) ayant fourni, dans ces derniers temps, d'abondants matériaux, le moment paraît opportun pour jeter un coup d'œil sur ce qu'ont produit les quatre localités, en attendant l'apparition, dans les Mémoires du Musée royal d'Histoire naturelle de Bruxelles, de la monographie que prépare l'un de nous (P. Teilhard) sur les Mammifères paléocènes de la Belgique.

II. Le Gisement d'Erquelinnes.

En 1880 M. A. Gravis, aujourd'hui Professeur de Botanique à l'Université de Liége, découvrait, dans les sablières d'Erquelinnes, les premiers restes de Mammifères paléocènes du pays, et il s'empressa d'en faire don au Musée de Bruxelles.[5]

L'année suivante (1881), M. A. Rutot, alors Conservateur au Musée, les signala à l'Académie sous le nom de *Pachynolophus Maldani*.[6] Il donna, en outre, une coupe du terrain, qu'il rapportait au Landénien supérieur.[7]

[1] A la frontière française, près de Maubeuge. Le gisement d'Erquelinnes comprend trois localités : Erquelinnes, Grandreng et Jeumont.

[2] Au nord de Landen, dans la Hesbaye.

[3] Leval-Trahégnies, à l'est de Binche.

[4] Au nord de Huy, dans la vallée de la Méhaigne.

[5] A. Rutot, 'Sur la Position stratigraphique des Restes de Mammifères terrestres recueillis dans les Couches de l'Eocène de Belgique' Bull. Acad. Roy. Belg. vol. i (1881) p. 514.

[6] A. Rutot, *op. cit.* p. 536.

[7] *Id. ibid.* pp. 516, 534, & pl. i, fig. 1.

Longtemps après (1909), l'un de nous (L. Dollo) y ajouta le *Coryphodon eocænus*.[1] Et, tout récemment, il fit entreprendre de nouvelles recherches dans le gisement, qui amenèrent la découverte, au même niveau, d'une faune de petits Mammifères. L'étude de ces restes, qui consistaient essentiellement en dents isolées, étant très délicate, ne pouvait être entreprise utilement que par quelqu'un s'étant déjà beaucoup occupé de ces formes sur de meilleurs matériaux (P. Teilhard).[2]

C'est ainsi qu'il y reconnut, notamment, les genres *Adapisorex*, *Omomys*, *Paramys* et *Sinopa*, représentés par des espèces que nous allons retrouver à Orsmael.

La description et la figuration de ces pièces feront partie de la monographie mentionnée au début de cette note.

III. Le Gisement d'Orsmael.

Ce gisement fut découvert, par M. Rutot, en 1883 : il le qualifia 'gravier base de l'assise supérieure de l'étage landénien au sud-est d'Orsmael.'[3] Et il en donna une coupe (*op. cit.* p. 47).

Dans ce gravier se trouvaient de nombreux débris, très fragmentaires, de Mammifères, de Reptiles et de Poissons.

L'un de nous (L. Dollo) fut envoyé aussitôt à Reims, par le Musée, pour y faire les premières comparaisons avec le zélé paléontologiste français Victor Lemoine. Dès ce temps (1884), la présence de *Plesiadapis* fut signalée à Orsmael.[4]

En 1905, au moment de l'installation de la Nouvelle Galerie des Vertébrés vivants et fossiles de la Belgique, au Musée de Bruxelles, une révision de la faunule d'Orsmael fut jugée nécessaire. Victor Lemoine étant mort, sa collection au Muséum de Paris, A. Thévenin (alors Assistant au Muséum) fut prié de faire cette révision. Le point le plus remarquable de son travail fut la découverte du *Phenacodus* dans nos matériaux.[5] Il en conclut à l'existence de la Faune de Puerco, du Nouveau-Mexique (Etats-Unis), en Belgique.

Les choses en restèrent là pendant longtemps. Cependant, vu l'importance de la question, et sollicité, à diverses reprises, par plusieurs collègues étrangers, de recommencer les fouilles, l'un de nous (L. Dollo) se décida à faire le nécessaire pour retrouver le gîte et l'exploiter. Le succès couronna ses efforts.

Après deux ans de recherches—parmi les autres travaux de l'Atelier de Paléontologie du Musée de Bruxelles de nombreux

[1] L. Dollo, 'The Fossil Vertebrates of Belgium' Ann. N.Y. Acad. Sci. vol. xix (1909) p. 109.

[2] P. Teilhard de Chardin, 'Les Mammifères de l'Eocène inférieur français et leurs Gisements' Ann. Paléont. vol. x (1921) p. 169.

[3] A. Rutot, 'Explication de la Feuille de Landen' Carte géologique détaillée de la Belgique, à l'échelle du 1 : 20,000. Bruxelles, 1884, pp. 43 & 44.

[4] *Id. ibid.* p. 44.

[5] L. Dollo, Ann. N.Y. Acad. Sci. vol. xix (1909) p. 109.

matériaux nouveaux furent recueillis, et, aujourd'hui, plus de mille dents de Mammifères landéniens d'Orsmael (dents dont la taille ne dépasse que rarement 4 millimètres) sont entrées dans les collections de l'établissement, sans parler d'autres petits ossements de ces Mammifères minuscules.

C'est alors que la Monographie sur les Mammifères paléocènes de la Belgique fut décidée par la Direction du Musée. Elle devait, naturellement, être confiée à l'auteur de la monographie sur les Mammifères de l'Eocène inférieur de la France (P. Teilhard).[1]

Voici un bref résumé de ses premières observations. Les formes dont la présence a pu être reconnue à Orsmael appartiennent aux groupes suivants :

(1) Didelphes.	(4) Condylarthrés.
(2) Insectivores.	(5) Carnivores.
(3) Primates.	(6) Rongeurs.

(1) Didelphes.—Les Didelphes représentent le plus petit élément de la faune d'Orsmael. Leurs dents, longues d'un millimètre seulement, rappellent beaucoup celles des *Peratherium.*

(2) Insectivores.—Plus du tiers des dents recueillies à Orsmael appartiennent à un type d'Insectivore dont il est possible, en partant d'une mandibule suffisamment conservée, de reconstituer avec une quasi-certitude la série dentaire presque complète. Elles doivent être rapportées à un même genre, qui paraît identique au genre *Adapisorex* du Thanétien de Cernay.

Les échantillons d'Orsmael, plus complets que ceux de Cernay, montrent que les *Adapisorex* diffèrent des Tupaidés actuels par la complication plus grande de leurs prémolaires, et notamment par la présence d'un tritocône aux prémolaires supérieures.

(3) Primates.—Les Primates sont représentés, à Orsmael, par un Chiromyidé et un Tarsidé. Le Chiromyidé (cf. *Plesiadapis*) n'est connu que par ses incisives supérieures, tricuspides comme celles du *Plesiadapis tricuspidens* de Cernay, mais beaucoup plus petites et bien plus comprimées latéralement.

Au Tarsidé (cf. *Omomys*) se rapporte toute une série de prémolaires et de molaires, qui rappellent extrêmement, par leur forme et par leurs dimensions, les dents des Anaptomorphidés américains.

(4) Condylarthrés.—Le Condylarthré le plus caractérisé trouvé à Orsmael est un petit *Phenacodus*, connu par une molaire inférieure et une molaire supérieure, très typiques.

On peut rapporter au même groupe des Condylarthrés un certain nombre de molaires isolées, de petite taille, qui paraissent assez semblables aux dents des Mioclénidés américains, mais qui pourraient aussi avoir appartenu à un Créodonte Oxyclénidé avec molaires supérieures sans hypocône et avec dernière molaire réduite.

[1] P. Teilhard de Chardin, Ann. Paléont. vol. x (1921) p. 169.

(5) Carnivores.—Les restes les plus communs des Carnivores, à Orsmael, sont de petites molaires inférieures et supérieures d'Hyénodontidés et de Miacidés, se répartissant dans trois genres et six espèces, au moins.

Les Mésonychidés sont représentés par une dent inférieure de *Dissacus*, et les Oxyclénidés par une molaire inférieure lémuroïde, de genre difficile à déterminer.

(6) Rongeurs.—Les Rongeurs forment une part assez importante de la faune d'Orsmael. Nous en avons recueilli, jusqu'ici, plusieurs astragales, un fémur, et de nombreuses dents (incisives, prémolaires, molaires). Ces dents montrent tous les caractères des *Paramys* et se rattachent, au minimum, à deux espèces.

IV. Le Gisement de Leval.

C'est encore à M. Rutot que nous devons la connaissance de ce gisement, dont il publia la description en 1901.[1] Il le plaça dans le Montien et en donna des coupes (*op. cit.* pp. 609, 610, 611 & 612). Aucun Mammifère n'y fut rencontré au début.

Mais, en 1909, l'un de nous (L. Dollo) y signala des restes d'un grand Mammifère, consistant principalement en un fémur (bien reconnaissable à son troisième trochanter), et qu'il rapporta au *Coryphodon*, en attendant une étude plus approfondie ou de meilleurs matériaux.[2]

A la suite de cette découverte, M. M. Leriche, Professeur de Géologie à l'Université de Bruxelles—et aucune autre raison, stratigraphique ou biostratigraphique, ne s'y opposant—transféra (1912) le gisement de Leval dans le Landénien supérieur.[3]

Plus récemment (1921), M. W. D. Matthew, Conservateur au Musée américain d'Histoire naturelle, à New York, a insisté sur l'impossibilité de la présence du *Coryphodon* dans le Montien.[4] Il a même exprimé ses doutes sur l'attribution des ossements de Leval au genre en question. Mais, puisque le gisement est maintenant remonté dans le Landénien, il semble que la difficulté biostratigraphique soit résolue.

Quoiqu'il en soit, celui d'entre nous qui s'est spécialisé dans le domaine des Mammifères fossiles (P. Teilhard) ne manquera pas de réexaminer ce problème à l'occasion de sa monographie sur les Mammifères paléocènes de la Belgique.

[1] A. Rutot, 'Sur la Découverte d'une Flore fossile dans le Montien du Hainaut' Bull. Soc. Belge de Géol. vol. xv (1901) p. 605.

[2] L. Dollo, Ann. N.Y. Acad. Sci. vol. xix (1909) p. 107.

[3] M. Leriche, 'Livret-Guide de la Réunion Extraordinaire de la Société Géologique de France à Laon, Reims, Mons, Bruxelles, Anvers' Bruxelles, 1912, p. 82.

[4] W. D. Matthew, 'Fossil Vertebrates & the Cretaceous-Tertiary Problem' Amer. Journ. Sci. ser. 5, vol. ii (1921) p. 213.

V. Le Gisement de Vinalmont.

Ce gisement, exploité par M. C. Fraipont, Professeur de Paléontologie à l'Université de Liége, consiste en 'fissures emplies d'un limon plus ou moins argileux, d'une carrière de calcaire carbonifère de Vinalmont (vallée de la Méhaigne), province de Liége.'[1] On y a recueilli, jusqu'à présent, des ossements de Mammifères, d'Oiseaux et de Reptiles.

L'un de nous (P. Teilhard) y a reconnu, parmi les restes de Mammifères, une dent qu'il a rapportée au genre *Hyopsodus* (*op. cit.* p. 360). Ce qui en fait probablement du Landénien supérieur.

Les recherches continuent :

> 'L'étude de ces ossements, que l'un de nous (M. Fraipont) a entreprise avec la collaboration du Dr. Muller, le Professeur Fourmarier devant étudier le gisement au point de vue géologique, n'est guère terminée, étant donnés l'état fragmentaire des ossements et le mélange des espèces.' (*Op. cit.* p. 357.)

VI. Conclusions.

Les quatre gisements de Mammifères paléocènes de la Belgique sont, tous les quatre, sparnaciens (=Landénien supérieur).

Les petits Mammifères d'Orsmael et de Jeumont (Erquelinnes), dont les restes ont été sélectionnés par un triage mécanique, ne peuvent nous donner qu'une idée très incomplète de la faune du Landénien supérieur.

La présence, dans les sables fluviatiles d'Orsmael, des Rongeurs, des Primates, de *Phenacodus*, jointe à l'absence des Multituberculés, et l'existence, dans les niveaux correspondants d'Erquelinnes, de la même faune (avec *Coryphodon* et *Hyracotherium*) indiquent clairement, pour ces dépôts, un âge sparnacien.

En fait, jusqu'ici (probablement à cause d'un éloignement trop grand des côtes pendant le Thanétien), aucun reste de Mammifères anté-sparnaciens n'a été recueilli en Belgique.

La persistance, dans le Sparnacien, des *Adapisorex* cernaysiens est un fait digne de remarque.

[1] P. Teilhard de Chardin & C. Fraipont, 'Note sur la Présence dans le Tertiaire inférieur de Belgique d'un Condylarthré appartenant au Groupe des *Hyopsodus*' Bull. Acad. Roy. Belg. vol. vii (1921) p. 357.

3. *On a* New Form *of* Blattoid *from the* Coal Measures *of the* Forest of Dean. By Herbert Bolton, D.Sc., F.R.S.E., F.G.S. (Read June 6th, 1923.)

[Plate III.]

I am indebted to Dr. A. Morley Davies, F.G.S., for the opportunity of examining and describing a blattoid forewing or tegmen collected upon the spoil-heap of the Harrow Hill Mine, Drybrook (Forest of Dean), during the course of a visit to that place by a party of students from the Imperial College of Science & Technology in 1921.

Description.

The wing is a right forewing or tegmen, and lies upon a block of grey shale containing plant-remains.

The tegmen is somewhat large for a blattoid, having a length of 44 mm., and a greatest width (across the anal area) of 19 mm: it is thus a little over twice as long as wide. The surface is densely chitinous and lustrous, with sunken veins, while the wing presents structures not hitherto seen, so far as I know, in any other British or European blattoid.

The outer (costal) margin is moderately convex along the proximal two-thirds, and then curves more abruptly inwards over the distal third, so that the wing-apex is carried backward towards the inner margin, to which it is joined by a short curve. The inner margin is convex over the anal area, concave in the middle, and a little convex over the distal cubital area, where it passes by the short curve mentioned into the blunt apex.

The double curvature of the inner margin imparts to the wing a somewhat humped appearance.

The costal area is very wide basally, somewhat triangular, and terminates in an acute angle beyond the middle of the wing.

The base of the wing is not complete, so that, with the exception of the cubitus and of the vein lying in the anal furrow, the union of which is indicated on the matrix, the characters and relationships of the basal portions of the principal veins cannot be determined. This is much to be regretted, especially in the case of the subcosta, which is represented by three sets of branches. The distribution and further ramifications of these three branches are shown in Pl. III. Near the point of origin of the third twig, the inner branch is joined by the second branch of the radius. A short looped vein passes from the point of attachment of the second branch of the radius with the subcosta to a little distance farther out.

It is possible that the second branch of the radius joins the subcosta only to come off again, rejoins more distally, and again comes

off to end in the small outermost fork. The condition is very unusual, and typical of the unusual variations seen in other parts of the wing.

The radius is a powerful vein giving off branches along the greater part of its length. Its distribution and branching are shown in Pl. III, where it will be seen that the first branch ends in the integument. The innermost twig unites with the distal part of the first branch of the radial sector for a short distance; they afterwards separate, and pass out to the wing-margin.

The radial sector arises immediately behind the origin of the first outer branch of the radius, and diverges widely, remaining unbranched until well beyond the middle of the wing, after which it sends off three long parallel branches, the first united to the innermost twig of the radius, as mentioned above (see Pl. III, fig. 2).

The median is, like the radius, incomplete basally, and, on the broken edge of the wing, shows an outer curve very suggestive of the basal union of the two veins. It remains single up to the point of branching of the radial sector, beyond which it branches as shown in Pl. III, the last twig uniting with the fifth outer branch of the cubitus.

The cubitus passes almost straight out from the base of the wing to the inner margin with very little curvature, and is characterized by giving off a series of outer and inner branches, those of the outer side being unbranched, and those of the inner much branched, many of the twigs failing to reach the margin. The details of the remarkable ramifications of this vein are shown in Pl. III.

The cubitus is very widely spaced, both from the median and from the anal furrow, and, like the median, passes diagonally across the wing to the end of the inner margin. The cubital is much the largest area in the wing.

The next inner vein ought to be considered with the evident cubitus, since, from indications shown on the matrix, the two were joined basally. This vein lies along the line of the anal furrow, and diverges widely from the cubitus, the marginal width of the area between it and the main stem of the cubitus being very great. It gives off two feeble outer branches, the more distal only reaching the margin quite close to the vein from which it arises.

The position of this vein in relation to the evident median is very similar to what is seen in some forms of the Protoblattoidea, and is especially suggestive of the condition seen in *Blattinopsis*, where an inner branch of the median similarly follows the line of the anal furrow. It is, in all probability, the inner median vein.

The anal area is convex, more than half the length of the inner margin, and crossed by seven anal veins, three of which are forked, the first anal being twice forked.

The interstitial neuration consists of a dense series of irregular cross-veins anastomosing laterally, and is strongly wrinkled on the apical portion of the wing.

Affinities.

The wing presents a number of special features. The crossing or union of the veins, such as is seen in the case of the twigs of the subcosta and second branch of the radius, and the union of the first branch of the radial sector to the most distal twig of the radius, are of unusual occurrence in the one wing, and can hardly be considered as likely to be a constant feature, although crossings and unions of veins are found in many species.

Characters resembling those found in different families and genera, and combined in this wing, are as follows:—

(1) The branching of the cubitus might well have developed from the condition seen in the genus *Blattinopsis* (Blattinopsidæ).[1]

(2) The wide spacing of the veins, especially the separation of the median and cubitus in the middle of the wing, is suggestive of the genus *Sysciophlebia* (Spiloblattidæ). Yet it differs from *Sysciophlebia* in the mode of branching and in the interstitial neuration, which is not (either in this wing or in *Sysciophlebia*) finely reticulated near the principal veins, except possibly in the anal area, and shows over the rest of the integument a dense series of close parallel cross-veins which unite laterally. Dr. P. Pruvost, of Lille University, with whom I have discussed this wing, agrees with me in this comparison, also in the two following.

(3) Affinities with *Phyloblatta* (Archimylacridæ) are suggested in outer branches of the cubitus which extend into the much-widened area between that vein and the median: as, for example, in *P. culvetti* Pruvost,[2] from an *Anthracomya* shale at Lens. The dense parallel cross-veins mentioned above are also an Archimylacrid character.

(4) The structure of the subcostal vein, with its divisions into three sets of branches, resembles that of *Trilophomylacris* Pruvost (Hemimylacridæ).

(5) The mode of branching of the subcosta and the presence of inner and outer branches of the cubitus are repeated in *Phylomylacris villeti* Pruvost (Hemimylacridæ).

Fuller consideration has led me to attach more importance to the character of the cubital branching than I did at first, and on that score I should class the wing as Hemimylacridian (Pruvost), were it not that the character of the interstitial neuration is wholly at variance with that group, while it is in agreement with Archimylacrids.

The probable solution of the relationship is that the wing belonged to an insect linking the families Archimylacridæ and Hemimylacridæ.

Whatever the generic relations may ultimately prove to be, the general assemblage of characters is altogether unlike anything

[1] This family is first described in my Commentry paper, not yet published.

[2] 'La Faune Continentale du Terrain Houiller du Nord de la France' 1919, p. 161 & pl. lx, figs. 9–11.

known to me from the British Coal Measures, nor have I found any record of a similar wing from the American coalfields. Dr. Pruvost states that he has not found anything similar, either in the Coal Measures of the North of France or in the Stephanian of Central France, nor is it known to him from the Belgian Coal Measures.

A new genus must be formed to receive the wing, and I therefore attach to it the name *Drybrookia*, and the specific name of *cubitalis*.

Drybrookia gen. nov.

Diagnosis:—Subcosta with grouped branches. Cubitus a powerful vein, with outer and inner branches. Anal area long.

Drybrookia cubitalis sp. nov.

Diagnosis:—Branches of subcosta with numerous twigs. Radius well spaced from cubitus; radial sector arising low down and reaching the wing-apex. Cubitus with secondary branching on the inner veins, and widely spaced from the median vein and the anal furrow. Interstitial neuration of close parallel cross-veins uniting laterally.

Type:—A right tegmen, Geological Museum, Imperial College of Science & Technology.

Horizon and locality:—Shales over the Coleford High Delf Seam, Harrow Hill Mine, Drybrook (Forest of Dean).

EXPLANATION OF PLATE III.

Fig. 1. Photograph of the right tegmen of *Drybrookia cubitalis*, × 2.
2. Diagram of the same, showing the venation, × 2. A=anal area; Cu=cubital area; M=median; Rs=radial sector; R=radius; Cs=subcosta; C=costa.

Discussion.

Dr. J. W. Evans thought that this interesting find in the course of a single visit by Imperial College students indicated the importance of local collecting work. Innumerable valuable specimens were lost, which might have been secured by the work of amateur geologists.

Dr. F. A. Bather congratulated the Author on having received so interesting a specimen and on the lucidity of his description. He enquired whether the peculiarities of the veins to which attention had been drawn indicated a wing in a stage of catagenesis or anagenesis.

Dr. W. D. Lang asked whether the fact that the Author considered the described specimen as partaking of the characters of the two families Archimylacridæ and Hemimylacridæ pointed to the artificiality of the families; or, to the described form belonging to a group which was ancestral to both families. He also asked

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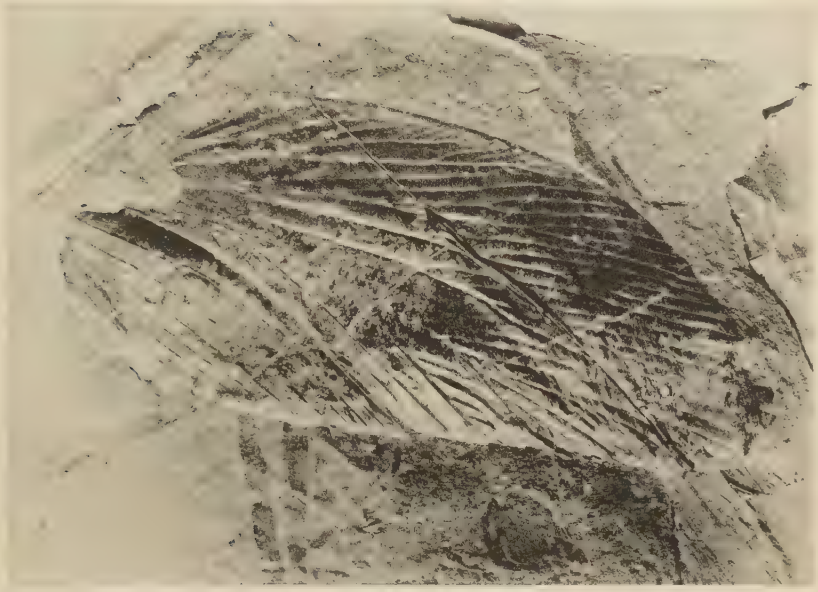
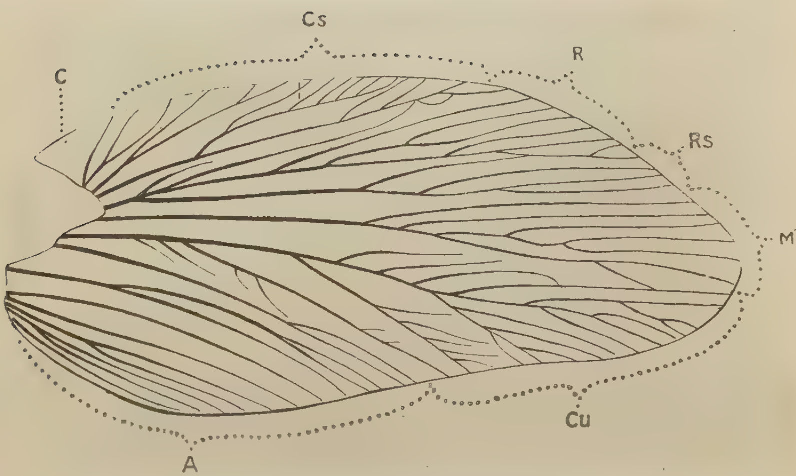


2



DRYBROOKIA CUBITALIS, gen. et sp. nov. ×2.

whether, in the Author's opinion, the Carboniferous Blattoids were the direct ancestors of the recent Blattids, or were an independent cockroach-like development from a more primitive and generalized stock—a stock which several times over may have given rise to other Blattoid and allied developments, and from which recent Blattids and allied groups finally sprang. And, generally, whether the several groups of Carboniferous Insects were directly ancestral to the corresponding recent Insect Orders; or, whether they were parallel developments from a more primitive stock, playing the part of the recent Orders without direct relationship to them, and bearing a corresponding relation to recent Insects as the Marsupials bear to the Placental Mammals.

The Author said, in answer to Dr. Bather, that the course of development of the Blattoid wing was not sufficiently understood to permit of any definite conclusions being drawn as to the course of progression or retrogression of venation. As he understood Dr. Tillyard (who had made a special study of the nymphal wings of recent insects), branching of the veins arose on the wing-border, the point of origin of the new branch afterwards moving along the main stem towards the base of the wing. The Author's own observations upon fossil Blattoids rather led to a different conclusion: namely, that new branches arose from the main stem in the body of the wing, and grew out into the wing areas between any two main veins, and might or might not reach the margin.

In answer to Dr. Lang's questions, there was no doubt that the families Archimylacridæ and Hemimylacridæ were artificial. Various writers interpreted the characters of these families differently. The true relation of the Blattoids one to the other, and to their ancestral origin, was not certainly known; but evidence was accumulating which might soon enlighten us upon this matter. The described insect-wing possessed characters joining the two families Archimylacridæ and Hemimylacridæ—as these are understood by him (the Author). The Carboniferous Blattoids are almost certainly the direct ancestors of living Blattids. Recent evidence seems to show a direct connexion between some of the Coal-Measure forms and others of Mesozoic age, and it would be a reasonable inference to suppose that this progression was continuous to recent times.

The Author believed that he had, in one case, determined an evolutionary sequence from a Palæodictyopteroid stock, through the Protoblattoids and Blattoids, and ending, so far, in the Triassic Period.

It was not possible yet to determine whether Blattoids were polyphylogenetic in origin or not. Briefly, the Author's impressions are that Blattoids will ultimately prove to have been the direct ancestors of recent Blattids, and that they had a polyphylogenetic origin. In the present state of our knowledge of fossil Insects it is not possible to say how they are related to Orders of living Insects.

4. Contact-Metamorphism *in the* Comrie Area *of the* Perthshire Highlands. By Cecil Edgar Tilley, Ph.D., B.Sc., F.G.S. (Read June 6th, 1923.)

[Plate IV.]

Contents.

I. Introduction.

British petrographic literature is now so enriched by the detailed descriptions of contact-metamorphic aureoles, associated with plutonic intrusions—investigations largely conducted by the officers of the Geological Survey, and partly by independent workers—that it might appear that an investigation of an additional contact-zone would bring to light little but the usual well-known mineral-assemblage of aureoles already investigated. In the case of the aureole surrounding the Carn Chois diorite-complex of Perthshire, moreover, an inspection of the 1-inch Geological Survey map would tend to confirm this view—not only as to the nature of the mineral-assemblages, but also as to their apparently restricted variety. The diorite-complex is shown as intruded almost completely within the Ben Ledi Grit stratigraphical zone, touching only at its southernmost point rocks essentially of argillaceous composition—the Aberfoyle Slate-band.

Here, then, are presumably sediments of a restricted range of composition; the hornfelses derived from them may be expected to show the same limit of variation.

The examination that I have been able to make of this aureole shows quite clearly, however, that such a restriction in chemical composition is far from being the case. The thermal products show a wide range of composition, and the mineral-assemblages in the inner zone of hornfelses include types which (I believe) have not been previously recorded from British contact-zones, and some

that I have not been able to match with any of the thermal products of extra-British contact-aureoles. Moreover, these unusual mineral-assemblages are by no means rare in the aureole itself, but have been recorded from numerous parts of the contact-zone.

Of greatest interest in this connexion are the abundant corundum- and spinel-hornfelses, the remarkable coarse fluor-violet cordierite-hornfelses of Creag nah Iolaire, and a group of hypersthene-bearing hornfelses (both those of free-silica type and those poor in silica).

Hornfelses conspicuous by their rarity are the calc-silicate varieties, for there are no important calcareous beds which enter the aureole of the diorite. Additional interest is aroused, in that one of the great epidiorite-sheets which intrude into the Dalradian sediments is involved in the aureole, and has suffered metamorphism, with partial to almost complete reconstruction.

These rocks I propose to describe in the following pages.

II. Previous Literature.

The only reference to contact-metamorphism in this region that I have been able to discover occurs in J. Nicol's[1] paper on the geological structure of the Southern Grampians, where he notes the hardening of the slates and their recrystallization, as they approach the igneous contact. The area was mapped by the Geological Survey on the 6-inch scale, the results appearing in the 1-inch map published in 1888, but no descriptive account of the area appears to have been written.

A short note on the nature of the intrusive rocks of Glen Lednock appears in an appendix to a paper on Garabal Hill, by B. K. N. Wyllie & A. Scott in 1913.[2]

III. Geology of the Comrie Area.

Only a short notice is necessary here, to indicate briefly the geological features of the area in which the Carn Chois diorite-complex is exposed. The Highland Border-fault in this region is developed immediately south of Comrie, trending in an east-north-easterly direction, and succeeded on its northern side by the weakly metamorphosed members of the Dalradian System.

Grits, slates, and a thick series of siliceous grits follow one another in ascending s t r u c t u r a l succession from the fault-zone. These beds have been correlated with similar rocks developed in the neighbourhood of Callander, away to the south-west: namely, with the stratigraphical groups (1) Leny Grits, (2) Aberfoyle Slates, and (3) Ben Ledi Grits.

The Aberfoyle Slate-band is a well-marked horizon which extends through the Forest of Glenartney, and strikes through Comrie itself.

The present exposure of the Carn Chois diorite is now almost

[1] Q. J. G. S. vol. xix (1863) p. 192.

[2] Geol. Mag. p. 544.

wholly confined to the Ben Ledi Grit-zone, and intrudes into the slate-band, only over one small area in the vicinity of Craig More, east-north-east of Comrie.

Original Grade of Metamorphism of the Sediments Involved in the Aureole.

All the sediments which enter the aureole of the diorite are in a low grade of metamorphism. The lowest grades appear in the south, and the metamorphism increases in a northerly direction. The representatives of the Aberfoyle Slates are well-cleaved rocks, in which the white mica and chlorite are now almost wholly reconstituted. The Ben Ledi Grits show a similar reconstitution. All these rocks, however, are included in the chlorite-zone of dynamic metamorphism, and within the area biotite never appears as a product of dynamic metamorphism.

The Carn Chois Diorite.

The disposition of this plutonic complex with regard to the intruded sediments is one of a distinctly transgressive nature.

In plan the exposure is roughly elliptical, with the major axis trending in a north-westerly direction, and thus almost at right angles to the dominant strike of the associated sediments. The dimensions of this stock-like mass are approximately 5×2 miles.

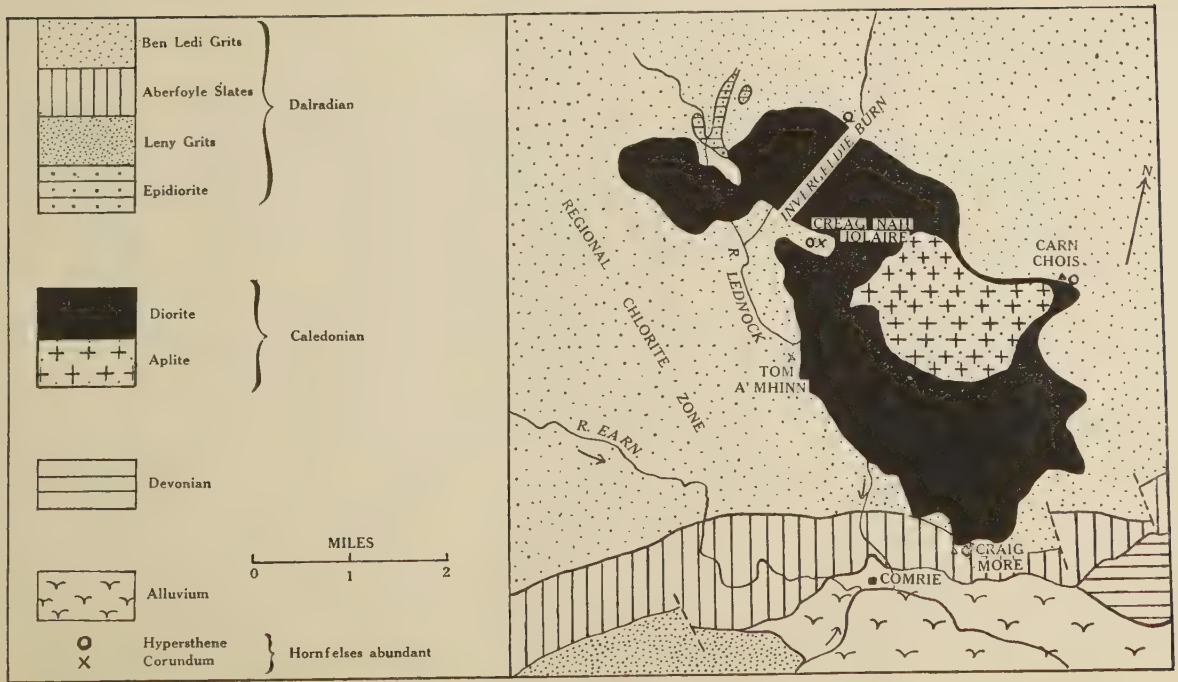
The main mass is composed of a moderately coarse biotite-hornblende-diorite, consisting of biotite, andesine, and hornblende, the subordinate constituents being quartz, orthoclase, iron-ores, apatite, and zircon. In some varieties (as, for example, the diorite on the summit of Creag nah Iolaire), diopsidic pyroxene enters as a dominant constituent. These diorites show considerable variation in size of grain, as was pointed out by Wyllie & Scott.

The diorite is pierced in its central part by a roughly rectangular mass, dimensions $1 \times 1\frac{1}{2}$ miles, of a fine-grained pink rock, described on the Geological Survey map as granite. This name, however, does not accord with the mineralogical and textural features of the main mass of the rock. Usually, it is distinctly poor in ferromagnesian minerals, biotite alone being sparingly present. The constituents are quartz, plagioclase (oligoclase-andesine), orthoclase, biotite, and magnetite. This mass of rock is best described as an aplite.

No detailed examination of this igneous complex has been made, and is indeed beyond the scope of this paper. Moreover, an exhaustive examination of the igneous petrology of the Carn Chois area is now being carried out by Dr. A. Scott, the results of whose work will (it is hoped) soon be available.

In the map on p. 26 the outlines of the Carn Chois mass are shown, these being taken from the 6-inch maps of the Geological Survey. Some alterations of the boundary were, however, found necessary, as at Invergeldie, east of Craig More, and in the

Geological sketch-map of the Comrie area (Perthshire).



vicinity of Carn Chois itself. The extent of these modifications can be seen on inspection of the 1-inch Geological Survey map of this area.

I may note here, however, particularly, the change observable in the neighbourhood of Invergeldie, close to Creag nah Iolaire. On the southern slopes of this hill, and north of Creag Liath, a tongue of sediment extends from Invergeldie and Coishavachan, and is probably continuous with the main mass of sediments on the opposite side of the Lednock valley at Creag Ghorm, and Creag nah Arairidh. The summit of Creag nah Iolaire consists of diorite; but a few yards below it the tongue of highly-metamorphosed sediment enters, and here attains a width of 400 yards.

On the Geological Survey map the 'granite' is shown as coming directly into contact with sediments along the whole of its northern border. There are few exposures in this area, but there is reason to believe that a thin strip of diorite intervenes between the aplite and the sediments. This can be seen in the main channel of the Carrock Burn, where diorite is exposed north of the aplite.

At Carn Chois the sediments are in contact with diorite 150 yards south of the summit, and the diorite extends beyond the boundary-fence running south-eastwards from the summit. These changes and others not specifically mentioned here can be readily made out, by comparing with the map now given the original Geological Survey sheet.

The contact-rocks described in the following pages owe their metamorphism essentially to the dioritic member of the complex.

IV. The Thermal Aureole in the Aberfoyle Slate-Band, Craig More.

The slate-band intercalated in the Ben Ledi Grits enters the aureole of the intrusion near Comrie, being cut by the southernmost protrusion of the Carn Chois diorite at Craig More.

Constitution of the Slate outside the Aureole.

The slate is a well-cleaved rock, with glossy cleavage-surfaces where still unaffected by the intrusion. It has suffered considerable reconstruction in the Comrie area, and cannot be included in Mr. G. Barrow's zone of clastic mica, as will be evident from the petrographic description.

The constituents are white mica, chlorite, quartz, iron-ores, leucoxenized ilmenite-grains, tourmaline, epidote, albite and albite-oligoclase, rutile, zircon, pyrites, and calcite. The essential constituents may be limited to the first four minerals, the remainder appearing as accessories may be absent. The white mica and chlorite, in regeneration under dynamic action, have developed a parallel orientation, and the two minerals are often intergrown. In certain calcareous layers epidote is authigenic, having crystallized *in situ*.

Changes Induced by Thermal Metamorphism.

The changes that can be made out as the diorite is approached can be presented in the following order:—(*a*) zone of spotted slates; (*b*) zone of biotite development; and (*c*) zone of cordierite development.

The thermal effects of the intrusion can be well studied by investigation of a series of rocks obtained in the vicinity of Craig More, in a continuous series of exposures from the Comrie-Crieff road near Tredegar to the contact, approximately 150 yards north of the summit of Craig More itself.

(*a*) Zone of spotted slates.—The first sign of thermal alteration in the slates is the development of minute spots, accompanied by a hardening or induration of the whole rock. The spots are usually dark grey or black, and are characteristically spread upon the cleavage-planes with a minimum extension across them. They seldom exceed 1/20 inch in diameter and are usually smaller. As seen on cleavage-surfaces, they vary in shape from roughly circular to ovoid. Essentially, they consist of the same minerals as those that characterize the rest of the rock, but in somewhat different proportions. In thin sections they are much less easily detected than in hand-specimens; they may have quite ill-defined boundaries, merging into the surrounding matrix. No chemical reconstruction is apparent. Between crossed nicols these spots become very obvious, for their richness in chlorite and white mica at once results in brightly-polarizing aggregates. The spots extinguish as a whole parallel to their longer axes, which are usually in the direction of cleavage. The fibres of white mica and chlorite are largely oriented in this direction, and consequently they are best seen when the cleavage is placed at an angle of 45° with the nicols.

In their first development the spots may assume an extension only in the cleavage-plane, and then cannot be recognized in sections cut perpendicular to it. The interstitial areas are richer in quartz; but no appreciable difference in size of grain between spots and matrix is usually apparent. This is a distinction from the observation on the spots of the outer aureole of some of the Cornish granites, where the spots are more finely grained than the surrounding matrix.

When the biotite zone is entered, the spots may still be preserved, and then biotite becomes a constituent of them in association with the other minerals. The spots are already developed at 450 yards from the contact, but they are not always persistent. The induration which sets in at an early stage, before biotite can be recognized in thin sections, gradually increases, with concomitant loss of fissility. Ultimately, the fissility disappears near the inner edge of the biotite-zone, and is completely lost with the entry of cordierite.

It is not easy to account for the early development of spotting

of this type. It is necessary to postulate an aggregation of the micaceous constituents and an orientation of the films. This is perhaps induced under the influence of interstitial solutions, and vapours derived both from the sediment and from the magma, with selective aggregation of directional minerals. Dr. J. S. Flett[1] has compared their production with that of concretions in argillaceous or calcareous sediments.

(*b*) Zone of biotite development. — The first sign of chemical reconstruction in the slates, as the contact is approached, is the production of little flakes of brown mica, strongly pleochroic and interspersed among the chlorite- and white mica-flakes. They may appear first around little grains of iron-ore. These flakes show a general tendency to parallelism with the oriented wisps of chlorite and sericite. They increase in size as the contact is approached, and their formerly well-defined orientation decreases in constancy. In this series of rocks the first sign of biotite development is observed at 290 yards from the contact; but, north of Tomperran, biotite is found as a thermal mineral at a distance of 450 yards from the actual contact.

(*c*) Zone of cordierite development.—The next mineral of importance arising as a metamorphic product is cordierite, and from its first entry at 150 yards it is found in all the hornfelses examined in that area. This cordierite zone may well be called the zone of true hornfelses: for, with the incoming of this mineral, the whole rock rapidly becomes completely reconstituted. Typical hornfelses from the Craig More inner zone comprise free-silica hornfelses rich in cordierite and rhombic pyroxene, and silica-poor hornfelses containing, in addition to cordierite, the minerals spinel and corundum, as also hypersthene.

V. The Thermal Aureole within the Ben Ledi Grits.

The Ben Ledi Grits have a considerable range of composition, frequent oscillation of sedimentary type being the rule, and this character is brought out in a very striking manner when the hornfelses along the contact are examined. In order to study progressive changes as the contact is approached, the region of the Glen Lednock valley from Crappich Hill may now be examined. As might be expected, the delicate evidence of thermal change, the incoming of spotting, is not now observed in gritty beds. The first marked effects can be seen in hardening and induration of the rock, which in its very early stages loses something of its fissile character. These incipient changes can be observed on the summit of Crappich Hill, where induration is very evident; and this is quickly followed by chemical reconstruction in the production of little biotite-flakes, which tend first to appear in the chlorite white-mica areas near

[1] Mem. Geol. Surv. (Sheets 351 & 358) 1907, p. 23.

granules of iron-ore. The first sign of authigenic biotite is here at 550 yards from the contact.

At 420 yards biotite is more abundant, and is profusely developed in small flakes at 310 yards, the original character of the rock still being preserved.

At 280 yards the rock is a true hornfels, and (being argillaceous) has developed andalusite in long prisms. Cordierite is also present. Biotite is in much larger flakes, and has taken on the deep red-brown colour characteristic of the mica of the inner parts of the aureole. This rock is completely reconstituted, and from this point we are in the zone of true hornfelses. These show considerable variety of type. Thus, proceeding towards the contact, we have

Andalusite, cordierite, corundum.	(230 yards)
Corundum, cordierite, spinel. Cordierite, quartz, biotite.	(180 yards)
Cordierite, plagioclase, quartz. Corundum, cordierite, spinel.	(160 yards)

The little hill of Tom a' Mhinn at this locality is very rich in corundum-bearing hornfelses.

There is no need to describe in detail the progressive changes in other parts of the aureole, as they are essentially similar to that described above. The entrance of reconstruction in the form of biotite development has an outer limit of 500 to 600 yards, not always constant. This is succeeded by the development of cordierite, and the rocks thereafter assume rapidly the character of true hornfelses, in which reconstruction is complete.

The thermal aureole is wider in the Ben Ledi Grits than is the case with the aureole enclosing the Aberfoyle Slate-band, as will be noted by comparison.

VI. Comparison of the Progression in the Carn Chois Outer Aureole with that in Contact-Aureoles of other Regions.

A survey of the changes induced in argillaceous rocks by plutonic intrusions, as revealed in the now numerous descriptions of thermal metamorphism, shows that the initial changes are of considerable variety. This variation largely arises from differences in mineralogical and textural composition of the rocks subjected to thermal alteration. The nature of the frequently described spots—which in general, whatever their constitution, are among the first visible signs of thermal alteration—is not always easily deciphered.

In the classic Steiger Schiefer, they arise by aggregation of pigment without any chemical rearrangement of the rock-mass. At Comrie, the spots consist simply of the same constituents as the rest of the rock, but with a greater percentage of white mica and chlorite.

Spots of analogous nature occur in the aureole of the Land's

End granite, although, if we may judge from the descriptions, biotite had already developed in the bulk of the rock.

Spots of a different character are common to all aureoles—namely, those consisting of andalusite or cordierite, which indicate chemical reconstitution. These are found in the Comrie area within the inner zone; but in some aureoles they precede in development any notable reconstruction of the matrix, appearing at a very early age, before biotite is developed. Such are some of the andalusite-spotted rocks of the Skiddaw aureole.

As remarked by Dr. A. Harker, this early reconstruction can be simply explained as a result of thermal alteration of kaolin-bearing shales or slates, andalusite normally arising, or, if magnesia is abundant, cordierite.

It is a very significant fact in this connexion that, where the Aberfoyle Slate comes within the aureole of the Carn Chois diorite, andalusite is a rare constituent, and when present is found only in the inner zone of hornfelses. Similarly, while cordierite is abundant, its first appearance is in rocks which have already developed biotite.

These facts are in harmony with the evidence of the unaltered slates themselves, for kaolin cannot be detected in them, the whole of the alumina being represented in sericite and chlorite. In the inner zone the abundance of cordierite and the rarity of andalusite are explicable, for such relations are to be expected where the original slate contained greater percentages of chlorite than is normally the case where andalusite-cordierite combined assemblages arise.

VII. The Zone of Hornfelses.

As the locus of intrusion of the diorite is almost wholly confined to the Ben Ledi Grit zone, it is to be expected that free-silica hornfelses will predominate. This is the case; nevertheless, the Ben Ledi Grits must contain many sedimentary bands in which quartz is not an abundant constituent, for we find throughout the aureole hornfelses in which no free quartz is present.

From the examination of the two areas just described it is seen that the first marked change is not developed at a constant distance from the igneous mass, being notably less distant in the fine argillaceous sediment. The variation in the width of the aureole and the width of the several zones is doubtless to be ascribed to more than one factor. First, the width of the aureole exposed at the surface is dependent on the gradient of the intrusion-surface; and, unless the junction be a vertical one, it does not represent the true width of thermal alteration. The few data that are at our disposal tend to show, however, that the junction has a steep gradient.

Next, it is necessary to consider chemically distinct types of rocks as possessing different susceptibilities to metamorphism; and, lastly, as the manner in which heat is transferred from the magma is dependent on two processes—conduction and convection

by vapours and solutions—the porosity of the rocks as a whole must play a part. It is conceivable that the more arenaceous and coarser sediments are more permeable to solutions than the fine-grained slaty beds. In them metamorphism might extend to greater distances than in argillaceous types.

From all parts of the hornfels zone, the different types can now be considered, and some attempt may be made to classify them.

It is convenient to deal with these in two divisions, (*a*) free-silica hornfelses and (*b*) silica-poor hornfelses: quartz being an essential constituent, whether dominant or only subordinate, in (*a*), and being completely absent in (*b*).

This division has proved suitable, on account of the large number of hornfelses recorded that are found to contain corundum and spinel, both minerals which are unstable in the presence of free silica. Any treatment of these thermally metamorphosed rocks as mineral-assemblages from the standpoint of the phase rule must be strictly limited to the inner zone of hornfelses in which recrystallization has been complete.

The rocks of the aureole in which a progression of thermal alteration is observed are obviously not in a condition of equilibrium, for the partial recrystallization has effected only those changes which have been the most susceptible to the influence of temperature.

Such rocks, unfortunately, do not often receive the attention which they deserve, for it is from them that the nature of the reactions which ultimately lead to a recrystallized assemblage is ascertained.

In the true hornfelses, however, all the early changes have been obliterated, and a complete reconstruction effected. It is here that the conditions for true equilibrium are most closely approached, and here therefore that the rocks should be examined in the light of the restrictions of the phase rule.

VIII. Constitution of the Free-Silica Hornfelses.

I shall adopt, as a basis for these assemblages, the treatment developed by Dr. V. M. Goldschmidt in his well-known work on the Christiania contact-rocks. This treatment embraces the free-silica hornfelses of the shale-limestone type of sediment. In Goldschmidt's classification the various classes of hornfelses are defined by the numerals attached to the various phase-assemblages. In this way the rocks are treated as systems of four components, (Mg, Fe)O, Al_2O_3, CaO, SiO_2, and in each of these assemblages quartz is an essential constituent.

Of the various classes represented, Nos. 1–7, with the exception of No. 6, are found among the hornfelses of the aureole; but there are no true hornfelses of Nos. 8 or 9 recorded.

Epidote-hornfelses, of which but two examples are recorded, are the only rocks richer in lime than that represented by a hornfels of Class 7. In most of these hornfelses biotite and potash-felspar

play an important part. Some there are in which biotite is wanting, especially those rich in cordierite. The importance of those minerals which are disregarded in this classification will be considered in the petrographical treatment that follows.

Hornfelses of Class 1.

Only a single example of an andalusite-cordierite-quartz hornfels is recorded from the aureole. This was collected at Crappich Hill 280 yards from the contact. It is a dense dark-grey hornfels, in which needles of andalusite can be made out with a lens. Under the microscope the rock is seen to be totally reconstituted. Long prisms of andalusite are developed up to 3 mm. in length, comparatively free from inclusions, these being magnetite and some flakes of biotite. In some of these the periphery is secondarily changed to white mica. These porphyroblasts are set in a ground-mass made up of cordierite, biotite, clear felspar, and quartz. Complete resolution of this ground-mass for recognition of quantitative proportions of the various minerals is not possible. The alkali-felspar is readily made out by its low refraction, and some of these grains are albite, but the majority are orthoclase. The biotite is strongly pleochroic in red-brown tints. Cordierite forms plates in the ground-mass enclosing the other minerals, especially biotite. Some of the cordierite is twinned, the crystals breaking up between crossed nicols into the characteristic twinned sectors.

White mica is now abundant, and to a less extent chlorite; but both these minerals are secondarily derived from the andalusite, and also from cordierite. The remaining minerals are magnetite, little prisms of rutile, and pleochroic grains of tourmaline. Apatite is an accessory.

Hornfelses of Class 2.

Only one representative of this class is found, and recorded from the lowest crags of Tom a' Mhinn, Glen Lednock.

The mineralogical composition is closely similar to that of the rock previously described, but andalusite is less abundant, and plagioclase enters. Quartz is abundant, and cordierite is largely altered to a yellow, isotropic, non-laminated product. The andalusite is in irregular prismatic sections, with the typical magnetite-inclusions.

Plagioclase is twinned after the albite law, its refraction is less than that of Canada balsam, and it has the low extinction-angle of albite-oligoclase. Orthoclase and biotite are both present as important constituents of the ground-mass.

Hornfelses of Class 3.

Hornfelses of the cordierite-plagioclase-quartz-biotite type occur in various parts of the inner aureole. A typical example from

the crags of Creag Gharbh, north of Invergeldie, may here be described.

It is a fine-grained dark bluish-grey hornfels, in which flakes of biotite are readily recognized. In thin section it is seen as an equigranular hornfels made up of quartz, plagioclase of the composition of andesine, biotite in red-brown flakes, and cordierite. This mineral, which encloses many biotite-flakes, is partly altered to the yellowish-green isotropic product. Magnetite is an accessory constituent.

This assemblage is interbanded with an assemblage composed of hypersthene-pseudomorphs and plagioclase, essentially a Class 5 hornfels. The hypersthene-pseudomorphs consist of a carbonate mineral and serpentine. It is clear that this band was originally richer in lime.

Biotite-plagioclase hornfelses.—Two rocks are mentioned here which must be grouped with this class. They are biotite-plagioclase hornfelses from the contact-zone at Invergeldie Burn. The constituents are essentially biotite and plagioclase of acid labradorite composition (25° zone perpendicular to 010). They resemble the hornfelses described above, with the exception that no cordierite could be detected in the base. The texture is equigranular. No quartz can be safely detected in this assemblage. The absence of cordierite is probably connected with this free-silica deficiency. The rocks must be closely related to the hornfelses of Class 3 *b* described below, in which spinel is present.

Hornfelses of Class 4.

Hypersthene-bearing hornfelses are comparatively abundant in the contact-zone of the diorite, and some of them belong to this class. A hornfels from the contact at Craig More is here described. The constituents are quartz, cordierite, hypersthene, plagioclase, biotite, orthoclase, and magnetite.

Plagioclase is quite abundant, developed in granules and idioblastic laths. The composition is that of an andesine (22° zone perpendicular to 010), and is optically positive. Zoning is present, and the central part is always more calcic than the shell, the variation extending from andesine to oligoclase of straight extinction. This zoning is evident in ordinary light, owing to the marked differences in refraction between the centre and the periphery. Cordierite is abundant, forming plates that show multiple twinning, which in longitudinal section exhibit overlapping lamellæ. It also occurs in numerous granules intergrown with the orthoclase, which never appears idioblastic.

Hypersthene forms subidioblastic prisms, showing its characteristic pink-green pleochroism, associated with plagioclase and cordierite. Lenticles largely made up of hypersthene-grains in a base of plagioclase are found: these doubtless arise from chlorite-rich layers in the original rock. Octahedra of magnetite are abundant, but biotite is only a subordinate constituent.

Hornfelses of Class 5.

A hornfels of the hypersthene-plagioclase type has been recorded on a previous page in connexion with the description of hornfelses of Class 3. A single rock of this composition, from the contact at Funtullich, is now recorded. It is a dark-grey hornfels, very rich in rhombic pyroxene. This is a typical pleochroic hypersthene, which, with biotite and magnetite, lies in a colourless base of plagioclase.

No cordierite nor any orthoclase can be detected in this base. There are a few crystals of a colourless to pale-green amphibole present, but in the greater part of the rock these are absent. The amphibole here takes the place of diopside, and its entry indicates that the composition of the rock is close to the border of Class 6. Magnetite is abundant, and apatite is an accessory.

Hornfelses of Class 6 are not recorded from the contact-zones; we pass, with increasing lime, to

Hornfelses of Class 7.

A number of these diopside-plagioclase hornfelses are recorded from the Invergeldie Burn contact. They are dark rocks, with glistening flakes of black mica. The constituents are quartz, diopside, plagioclase, biotite, orthoclase, and accessory apatite. The diopside is subidioblastic, of a pale-green tint, but not sensibly pleochroic, with a wide extinction-angle. An incipient development of bluish-green amphibole is to be noted. Biotite is abundant, in well-developed flakes showing pleochroism (pale yellow to dark brown). The reddish-brown tint of the more argillaceous hornfelses is here less noticeable. The ground-mass is made up of abundant quartz, plagioclase, and orthoclase. The plagioclase is a labradorite. It forms aggregates of tiny granules between the quartz-grains, or may crowd the quartz- and orthoclase-grains, yielding a sieve-like texture. (See Pl. IV, fig. 1.)

From the same locality comes a rock in which hornblende largely takes the place of pyroxene. Pyroxene is only a subordinate constituent among the hornblende individuals. The diopside may form a core to hornblende-grains; but the relationship is not solely paramorphic, for the hornblende possesses its own crystal form. This rock appears to be an example of a hornfels, either of Class 6 or of Class 7, which has developed hornblende from original pyroxene during the cooling of the rock, being a readjustment to the conditions of lower temperature. Both these rocks were collected at the actual contact.

Amphibole-hornfelses of the outer zone will be described on a later page.

The only rocks richer in lime than those represented by Class 7 are two epidote-hornfelses, collected from the contact near Craig More. There are no limestone-bands which come within the

aureole, so that rocks corresponding to Class 8 or Class 9 are not developed.

So far, in describing the free-silica hornfelses of the aureole, I have been dealing with rocks the composition of which is confined within the normal shale-limestone series of sediments. There is, however, a large number of hornfelses which cannot be strictly treated within this series. They can, nevertheless, be derived from the hornfelses of Class 1, by increasing the magnesia and ferrous-oxide content. These rocks are practically free from plagioclase, and may be considered as non-calcic hornfelses.

In a shale of normal composition (Al_2SiO_5) is a typical contact-mineral. The presence of this mineral is inhibited by excess of potash or of magnesia. In the former case, andalusite gives place to orthoclase or biotite; but this method of development must be quite rare, for high potash in a sediment is nearly always accompanied by high alumina. The second case is much more common, and will be discussed here. Magnesia and ferrous iron enter for the most part as chlorite. Andalusite, in this case, gives place to cordierite. This may be appropriately represented by an ideal equation of the type

$$2Al_2SiO_5 + 2MgO + 3SiO_2 = Mg_2Al_4Si_5O_{18}.$$

We pass then from the common andalusite-cordierite hornfels of Class 1 to a hornfels containing cordierite alone, and ultimately to a cordierite-hypersthene type with further increment of magnesia, thus

Class 1. Andalusite, cordierite (quartz, biotite, orthoclase).
Class 1, Mg. i. Cordierite (quartz, biotite, orthoclase).
Class 1, Mg. ii. Cordierite, hypersthene (quartz, biotite, orthoclase).

Rocks richer in magnesia than this do not occur in the zones of this aureole.

Hornfelses of Class 1, Mg. i: Cordierite-Quartz-Hornfelses.

The hornfelses included here can be divided into (*a*) biotite-rich types and (*b*) biotite-free types. There are naturally intergradations.

(*a*) Biotite-rich types.—A hornfels from the summit of Carn Chois is of this type. It is a blue-grey rock, with a resinous lustre given by the abundant cordierite. The constituents are quartz, cordierite, orthoclase, biotite, magnetite, and pyrite. Biotite occurs in red-brown, strongly pleochroic flakes. The cordierite and orthoclase, and to a less extent quartz, form an intimate intergrowth in the ground-mass. The cordierite may, however, form plates in which there is little intermixture of other minerals: in such cases the multiple twinning can be readily made out. While the quartz- and orthoclase-grains are clear and colourless, the cordierite has a grey appearance in ordinary light, possibly due to submicroscopic inclusions. Its refraction is slightly greater than that of quartz. A feature of the potash-felspar that may be

here remarked is the small optic axial angle of this mineral, thus approaching in this respect the sanidine type rather than the normal orthoclase type: the same feature can also be observed in some other hornfelses. Iron-ores are but sparingly present. (See Pl. IV, fig. 2.)

In another hornfels of this type from the contact east of Charles's Wood, north-east of Comrie, the cordierite has a somewhat different habit. Apart from its presence in independent crystals, it occurs as small granules filling poikiloblastically plates of quartz or orthoclase, with a typical sieve-texture. The cordierite in this rock is largely changed to the yellow-green alteration-product.

(*b*) Biotite-free types.—These types differ from the preceding, not only in the complete absence of brown mica, but in greater percentages of alkali-felspar, cordierite, and magnetite. The proportion of biotite to these latter minerals indeed shows a rough reciprocal relation, and we can have little doubt that, under the conditions prevailing, the mica is largely represented by them. These rocks occur in all parts of the aureole: some of them are exceedingly fine-grained. The cordierite is readily distinguished by forming, even here, relatively large crystals: it encloses the other minerals (quartz, alkali-felspar, and magnetite).

Some of these rocks are banded types, the banding of which is due to the development of linear strings of magnetite. There can be little doubt that this represents an original heterogeneity in the slates from which these rocks are derived, the magnetite-rich bands representing the layers richer in chlorite or in iron-ores. In the biotite-rich hornfelses this banding is also apparent; but here it is formed by layers very rich in brown mica. A similar explanation holds for these bands also: the formation of biotite was, however, possibly controlled by the active mass of water.

The composition of a rock of this class (1, Mg. i) can be illustrated by an analysis of a cordierite-quartz-biotite hornfels from Abbenstein (Harz), described by O. H. Erdmannsdörffer[1]:—

	I.
SiO_2	59·83
Al_2O_3	17·47
Fe_2O_3	4·09
FeO	3·93
MgO	3·70
CaO	0·49
Na_2O	1·08
K_2O	4·42
H_2O	3·80
TiO_2	0·93
P_2O_5	0·18
SO_3	0·13
Total	100·05

[1] Jahrb. Preuss. Geol. Landesanst. vol. xxx (1909) p. 357 (Eckergneis-facies).

When the foregoing analysis is compared with analyses of rocks of Class 1 & Class 3, the points of distinction are at once evident: namely, the higher $RO : R_2O_3$ ratio compared with Class 1 hornfelses, and the low percentage of lime compared with Class 3 hornfelses.

Hornfelses of Class 1, Mg. ii : Cordierite-Hypersthene-Quartz-Hornfelses.

Rocks of this category are the characteristic hypersthene-bearing hornfelses of the aureole. A type from Creagh nah Iolaire may be here described. It is a blue-grey rock, with a resinous fracture indicative of a high content of cordierite. The constituents are cordierite, hypersthene, orthoclase, and biotite; quartz is subordinate. Magnetite and apatite are accessories. (See Pl. IV, fig. 4.)

Hypersthene is very abundant, and the subidioblastic grains may reach 1·5 mm. in diameter. It may be intergrown with the cordierite-orthoclase base in such a way that isolated prisms similarly oriented are separated by these constituents. The pleochroism is strong, and the mineral is free from alteration.

The biotite is of the usual red-brown pleochroic type. The dimensions are generally less than 0·3 mm., but flakes reaching 1·5 mm. in length are also to be observed in these rocks. Very often, the biotite possesses a typical sieve-texture, due to the enclosure or intergrowth of the cordierite and orthoclase. In some of the types, a faint smoky-blue to colourless pleochroic tint can be distinguished in the cordierite, the scheme in these thin sections being

(Z, Y) smoky-blue; X colourless.

The principal distinction of these rocks from the calcic hypersthene-hornfelses is the greater abundance of cordierite and the absence of plagioclase.

One of the first hypersthene-bearing hornfelses to be described belongs to this class. This is the hornfels described by Ramsay from the Umptek nepheline-syenite contact. Its analysis may be reproduced here as representative of the class, and with it, for comparison, two other hornfelses of Class 1 and Class 4 respectively:—

	II.	III.	IV.
SiO_2	58·66	62·80	58·28
Al_2O_3	18·86	19·74	17·98
Fe_2O_3	6·62	0·00	2·42
FeO	5·10	1·98	6·52
MgO	5·10	1·34	4·88
CaO	0·68	0·87	2·01
Na_2O	2·81	1·22	1·39
K_2O	2·93	6·56	4·29
TiO_2	n.d.	1·36	0·21
Accessory	0·63	3·85	2·43
Totals	101·39	99·72	100·41

II. Cordierite-hypersthene-hornfels (Class 1, Mg. ii) nepheline-syenite contact, Umptek. W. Ramsay, Fennia, vol. ii (1894) No. 2, p. 51.

III. Andalusite-cordierite-hornfels (Class 1) soda-granite contact, Gunildrud. V. M. Goldschmidt, Vid. Selsk. Skrifter (1911) No. 1, p. 148.

IV. Cordierite-hypersthene-plagioclase-hornfels (Class 4) essexite contact, Sölvsberget. *Id. Ibid.* p. 162.

Inspection of these analyses indicates very clearly how the mineralogical composition is dependent on the $RO : R_2O_3$ ratios, as has been noted above.

Sandstone Hornfelses.

No detailed description of these rocks, which are abundant throughout the aureole, need here be given, for they present the same features as the more argillaceous types previously considered, the main distinction being the greater abundance of quartz. A few peculiarities may, however, be noted at this point.

(1) Grit, Devil's Cauldron, Lednock River.—This rock was collected at a distance of 480 yards from the contact. It has an indurated appearance, but no important reconstitution has been effected. It represents a rock from the outer limit of the aureole, where biotite is just beginning to develop. Under the microscope its clastic character is very evident. The clastic grains include quartz with well-marked strain-shadows, and turbid acid felspar (both albite and orthoclase), the latter much sericitized. Chlorite, iron-ores, and a little thermal biotite complete the rock.

(2) A second example, 350 yards from the contact, taken from the aureole at Creag an Fhithich, is richer in authigenic biotite, which has a very obvious association with iron-ores. The clastic character of the quartz- and felspar-grains is still evident, and the former show the characteristic strain-shadows. In the next stage cordierite begins to appear; with it may be associated minute grains of a pale-green spinel, but the latter mineral is never in contact with quartz. At this stage undulose extinction in the quartz is much less evident. Partial recrystallization has tended to eradicate it, and the large original clastic grains are now not single grains, but a mosaic of clear, uniformly extinguishing quartz.

As some of these rocks show, the strain-shadows in the clastic grains may persist into the outer part of the hornfels zone; but in the inner zone most, if not all, of this undulose extinction has disappeared. The relations of the quartz and felspar in the inner zone are not without interest. A rock in the zone of hornfelses at Craig Arairidh, south of Invergeldie, shows a granophyric intergrowth of quartz and alkali-felspar. These intergrowths are very closely associated with masses of cordierite enclosing well-defined

octahedra of magnetite. We thus may have a central elongated core of cordierite-granules, with a periphery of granophyric quartz-orthoclase intergrowths. In this rock the large quartz-grains still show some trace of undulose extinction.

Some of the Ben Ledi Grits exhibit a close banding, siliceous layers interdigitating with more argillaceous layers, the thickness of the latter varying from 1/16 to 1/4 inch. When converted into hornfelses these rocks present a striking appearance, the argillaceous layers developing into dense bluish-black lines separated by grey siliceous bands. On weathered surfaces this gives rise to a ribbed structure, due to the selective erosion of the darker bands.

I may briefly describe such a rock from the aureole at Tom a' Mhinn, 180+ yards from the contact. The siliceous bands consist of clear unstrained quartz in interlocking grains, with turbid alkali-felspar and scattered flakes of biotite and secondary chlorite.

The dark bands are seen to consist of biotite, cordierite, magnetite, and green spinel, with some alkali-felspar. The arrangement is often such that the interior portion consists of cordierite with magnetite- and spinel-inclusions, encased by an external fringe of biotite-flakes. Here, within a width of 1/8 inch, we have a cordierite-hornfels rich in spinel, but distinct from the surrounding sandstone-hornfels. The preservation in such excellent condition of the oscillatory composition of the original sediment is admirably indicated.

Epidote-Hornfelses.

From one locality only are recorded hornfelses richer in lime than those of Class 7: namely, at the contact with diorite, 600 yards north-west of the summit of Craig More. Here, from an originally calcareous band, epidote-hornfelses have arisen.

These rocks consist essentially of quartz, epidote, and small amounts of green hornblende. Accessorily present are orthoclase, sphene, plagioclase, secondary chlorite, and calcite. Quartz is the most abundant constituent, developed in interlocking grains.

The epidote is always xenoblastic, of negative optic character, in some sections twinned on 100, the pleochroism being marked in yellow-green tints.

One of these rocks is of especial interest, owing to the occurrence of a thin band of plagioclase-spinel composition. It is sharply separated from the epidote-bearing bands. The spinel occurs in a plagioclase-base, in the form of minute drop-like grains of brown-green colour. Cordierite could not be detected.

These epidote-hornfelses correspond in composition to Class 8 hornfelses. Under the prevailing conditions, however, water has entered into the constitution of the lime-alumina silicate, epidote arising in place of grossularite.

Amphibole-Hornfelses of the Outer Zone.

In describing the hornfelses of Class 7 above, certain amphibolic types have been noted which are to be ranged either in this class or in Class 6. In the outer parts of the aureole occur certain amphibole-hornfelses, in which there is reason to believe that the conditions for the production of pyroxene were never realized, and so amphibole appeared in its place. Hornfelses of this type occur, for example, at Tom a' Mhinn 180+ yards from the contact, and on the crags of Creag Gharbh, near Invergeldie. Here the amphibolic type is at a distance of 350 yards from the contact. They are very similar in character: the constituents are quartz, plagioclase, hornblende, magnetite, and apatite.

Biotite is almost completely absent in both of these rocks. The plagioclase is an acid type having a refraction less than that of quartz, and is of albite-oligoclase composition in one rock: in the other it is oligoclase-andesine. In another type the quartz is present in large grains, which still preserve the strain-shadows of the original clastic grains.

The low content of potash that these rocks possess and the comparatively acid character of the plagioclase distinguish them from Classes 6 & 7. They possibly represent a quartzose chloritic type of sediment, and may be compared to a sediment of the Green-Bed type in other parts of the Comrie area.

IX. Constitution of the Silica-poor Hornfelses.[1]

We can derive from the free-silica hornfelses of Class 1 the following silica-poor hornfelses, according as we abstract silica from andalusite and cordierite:—

Class 1 (*a*) Andalusite, corundum, cordierite.
(*b*) Corundum, cordierite.
(*c*) Corundum, cordierite, spinel.
(*d*) Corundum, spinel.
(*e*) Corundum, spinel, andalusite.
(*f*) Spinel, andalusite.
(*g*) Spinel, andalusite, cordierite.

Class 2 may yield similar rocks where some plagioclase is present. Similarly, Class 3 hornfelses give rise to

Class 3 (*a*) Cordierite, spinel, plagioclase,
(*b*) Spinel, plagioclase,

[1] The classification of the corundum-spinel hornfels is shortly considered in an earlier paper; see Geol. Mag. vol. lx (1923) p. 101. For hornfelses containing rhombic pyroxene, see a subsequent paper (*ibid.* p. 410). Since the appearance of these articles, P. Niggli (in Fortschritte d. Mineral. &c. vol. viii, 1923, p. 70) has contributed a paper on the mineral assemblages of the Kata rocks, which explores some of the ground already covered by the present writer. When, however, Niggli concludes that cordierite-spinel, and enstatite-spinel, assemblages are 'presumably unstable', I confess that I am unable to follow him.

and Class 4 of the free-silica hornfelses yields

Class 4 (*a*) Cordierite, spinel, hypersthene, plagioclase,
(*b*) Spinel, hypersthene, plagioclase.

Many of these are to be found among the thermal products of this aureole, and are described below.

Class 1 (*a*) Andalusite-Corundum-Cordierite-Hornfelses.

One representative of this class is recorded from the contact-zone. It was collected at a point 230 yards from the contact, below the summit of Crappich Hill. In addition to the above-mentioned minerals, biotite, orthoclase, and magnetite are present as primary phases.

The andalusite builds long prismatic crystals measuring up to 4 mm. in length, with strongly developed cleavage. The sole inclusions that are not numerous are irregular grains of magnetite. Only at the periphery has sericitization developed.

Cordierite forms rounded to ovoid crystals, enclosing numerous crystals of biotite and magnetite. Much of it is now represented by aggregates of white mica; but, in those spots where cordierite-substance is still preserved, pleochroic haloes may still be visible. These ovoid crystals are usually 0·50 to 0·75 mm. in diameter.

Corundum is abundantly developed in this rock, in irregular and ragged grains, with the characteristic high refractive index. Some of these show well the peculiar pleochroic spots and patches irregularly diffused through their substance. The only inclusions are little grains of iron-ore: these grains never exceed 0·5 mm. in diameter, and are usually much smaller.

The ground-mass in which these minerals are set consists essentially of a deep-brown pleochroic biotite, associated with clear, colourless potash-felspar. No definite white mica can be recognized.

Class 1 (*b*) Corundum-Cordierite-Hornfelses.

Three rocks of this class are recorded from Tom a' Mhinn, Carn Chois, and Creag nah Iolaire. Here neither spinel nor andalusite occurs.

The rock from the first locality (160 yards from the contact) may be here described. It is a typical dark hornfels, with small glistening flakes of brown mica. Very small venules of quartz-felspar composition penetrate it, and knots of the same minerals. These are derived from the intrusion.

Cordierite, where altered, shows the development of the yellow isotropic alteration-product. The corundum reaches dimensions similar to those in the rock previously described; but here more idioblastic crystals are the rule, so that good hexagonal cross-sections and rectangular sections are seen. Some of these grains are surrounded by white mica-blades (not margarite), associated with orthoclase, and are perhaps of pneumatolytic origin. More commonly, however, the enclosing mineral is orthoclase alone.

The ground-mass minerals are again essentially biotite and clear orthoclase. The knots and venules of igneous origin are well shown in the thin sections. Corundum is always protected from the quartz of these by a barrier of orthoclase.

Class 1 (*c*) Corundum-Cordierite-Spinel-Hornfelses.

These are by far the commonest of the hornfelses of the silica-poor type, derived from Class 1, in the aureole.

Twenty-five rocks of which sections have been cut belong to this assemblage. They are characteristic of the inner zone; but, as a hornfels from Clathick Burn indicates, they may extend out as far as 270 yards from the contact. The great majority come from within 100 yards of the contact.

A rock from Tom a' Mhinn is a beautiful hornfels of this type. It is a dark resinous rock, showing big dark spots of cordierite. The constituents are (in addition to the above) biotite, magnetite, and a small amount of orthoclase.

Cordierite is extremely abundant, forming the well-developed spots seen in the hand-specimen, reaching in certain ovoid crystals a length of 6 mm. The longer axes of these ovoid crystals are oriented in a common direction. These may be composite prismatic twins, and show in longitudinal section parallel bands, as in the albite-twins of plagioclase. Inclusions are numerous, and include drop-like grains of a pale-green spinel and magnetite.

Cordierite is also an abundant constituent of the ground-mass, with biotite. The typical alteration is the yellow isotropic material, but aggregates of white mica also appear pseudomorphing the spots. Apart from a few idioblasts of corundum, the bulk of this mineral is found in the ground-mass in very small irregular grains, associated with the biotite and cordierite.

The biotite never forms a prominent inclusion in the cordierite-spots, and a very striking appearance is given to the slides by these biotite-free cordierite ovoids immersed in a biotite-rich ground-mass.

From among other hornfelses of this type I wish to draw attention to other features, both mineralogical and structural. The individual minerals may now be separately described.

Corundum.—Idioblastic corundum commonly shows either hexagonal or rectangular outlines. Some idea of the habit of these idioblastic crystals may be gained from the various sections available. Commonly, we find hexagonal prisms elongated parallel to the vertical axis. The rectangular sections often show the parting parallel to the base, and have a negative elongation. These sections, when showing the blue spots, are pleochroic with reference to these, thus

O = sapphire-blue, E = sea-green.

The corundum may possess a turbid interior of a grey-yellow colour, surrounded by a periphery of colourless corundum. In the sections parallel to the axis *c*, long tapering or barrel shapes may be observed, due to the development of a steep hexagonal bi-pyramid.

The habit of flat crystals elongated in the basal plane is much less common, but is seen in some sections. These are recognized by their positive elongation and a parting developed parallel to their length.

Cordierite.—There is little to add with regard to this mineral. The refraction is always higher than that of Canada balsam. Where the cordierite is idioblastic, the habit is prismatic. Twinning is very common, yielding composite twins, which show parallel bands in vertical section, and in cross-sections hexagonal forms in which opposite sectors extinguish simultaneously. The twin-plane is here parallel to 110. Yellow pleochroic haloes around minute grains of zircon are quite common. In prismatic sections, the irregular overlapping of the twinned bands gives rise not infrequently to a type of chequer-structure, as seen in chequer-albite. The cordierite of these rocks is always widely biaxial, with optic negative character.

Spinel in these rocks seldom forms large independent crystals; but individual grains may be aggregated together to form large composite masses. The mineral is typically developed in little rounded grains, immersed in cordierite, or associated with corundum. It is always a green spinel. It may also be associated with magnetite-grains, forming usually an irregular mantle, or enclosed within them.

Very remarkable are the clusters of spinel which associate themselves with cordierite and alkali-felspar. These clusters vary from ovoid masses of spinel-grains in a cordierite-base to long strings, which have a linear arrangement very similar to the linear aggregates of magnetite also seen in these rocks. These linear clusters often show a parallel disposition among themselves, as if conforming to the original bedding-plane of the rock, but the long axes of other clusters may diverge from this direction.

The parallel arrangement of the magnetite-spinel linear aggregates corresponds closely to the layers of matted chlorite which are so common in the original slates, from which they arise, and is of genetic significance, as will be indicated below.

When idioblastic, the spinel-grains give rectangular and rhomb-shaped sections of octahedra. The only alteration that spinel is seen to undergo is a development of a serpentinous product.

There is a very evident relation between the quantitative amounts of biotite on the one hand, and the amounts of spinel and magnetite on the other, in these rocks: this relation is reciprocal. When biotite is abundant, spinel and magnetite are less abundantly

present. When biotite is in small amount, there is a corresponding increase in the quantities of spinel and iron-ore. Other changes go hand in hand with these, and will be discussed below.

Orthoclase is a very constant constituent of these hornfelses, and is readily discovered by its refractive index. As a constituent of cordierite-masses in the form of small, intergrown, irregular grains, and as a ground-mass for corundum, it is especially common. This potash-felspar never shows any trace of microcline twinning, and in this respect differs from the potash-felspar of rocks arising under a high grade of dynamothermal metamorphism. As a constituent of the ground-mass of porphyroblastic types, it is intimately associated with biotite. In a certain degree, the quantitative amounts of biotite and orthoclase bear some relation. In the biotite-free types orthoclase is often very abundant.

Plagioclase is not an essential constituent of these rocks, but is sometimes locally abundant. This is the case with certain types poor in corundum: such rocks can be considered as derivatives of Class 2 of the free-silica hornfelses. As albite, it may be present among the orthoclase-aggregates, and in the fine-grained types it is difficult to distinguish from that mineral.

Biotite.—The biotite of these rocks is the common, deep red-brown, haughtonite type, showing strong pleochroism. Usually, the flakes are arranged without any dominant orientation. It may, however, develop in linear clusters, and then is strongly suggestive of development from chlorite-strings of the unmetamorphosed rock. As noted above, biotite may be completely absent in some of these hornfelses.

A dark resinous-lustred hornfels of the corundum-cordierite-spinel type has been analysed. The mineralogical features of the actual analysed rock may here be shortly summarized.

In addition to the three minerals mentioned above, alkali-felspar, iron-ores, biotite, apatite, and zircon are present.

Biotite does not exceed 0·5 per cent. in amount, the rock being chosen for analysis for that reason.

Clusters of spinel-grains, linear or lenticular in cross-section, are a peculiar feature of this rock. Numerous pleochroic haloes occur in the cordierite. The alkali-felspar is all of lower refraction than the cordierite or than Canada balsam, and forms a spongy intergrowth with the cordierite; but it is also present forming a peripheral ring of grains to nuclei of corundum.

The analysis of this rock is given on p. 46, under (V).

	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	39·40	45·30	38·85	59·6	57·99	56·02
Al_2O_3	35·86	30·51	35·71	23·9	23·42	21·61
Fe_2O_3	trace	0·24	1·63	—	0·49	1·36
FeO	8·79	8·80	7·78	5·8	5·06	5·97
MgO	3·57	3·11	2·59	2·4	1·20	2·96
CaO	2·15	0·90	0·37	1·4	1·65	1·22
Na_2O	2·10	1·65	2·39	1·4	1·32	1·26
K_2O	3·84	4·84	4·55	2·6	3·50	2·83
H_2O+	1·02	1·05	5·17	0·9	3·39	4·90
H_2O-	0·29	0·26				
TiO_2	2·00	1·48	1·88	1·3	0·32	0·74
P_2O_5	0·82	0·12	—	0·6	—	0·02
MnO	trace	0·20	—	—	—	0·05
NiCoO	trace	0·02	—	—	—	—
CO_2	nil	trace ?	—	—	1·12	0·91
S	0·09	1·32 FeS_2 FeS	—	—	0·91	0·35
SO_3	trace	0·04	—	—	—	—
Cl, F	—	0·08	—	—	—	—
C	—	0·17	—	—	—	—
		0·03 BaO				
Totals	99·93	100·12	100·92	99·9	100·37	100·20

V. Corundum-cordierite-spinel-hornfels, Tom a' Mhinn, Glen Lednock.

VI. Corundum-cordierite-spinel-hornfels, Ascutney Mt. (Vermont), R. A. Daly, Bull. U.S. Geol. Surv. No. 209 (1903) p. 29.

VII. Chloritoid-sericite-schist, Alpi Apuane (Italy). E. Manasse, Atti Soc. Tosc. Sci. Nat. Mem. vol. xxvi (1910) p. 139.

VIII. Analysis V, recalculated with addition of silica, weighted 100 grams to 50 grams SiO_2.

IX. Culm-shale, Klausthal (Harz), O. H. Erdmannsdörffer, Jahrb. Preuss. Geol. Landesanst. vol. xxx (1909) p. 336.

X. Slate, Bolivar, Bartow County (Georgia), T. N. Dale, Bull. U.S. Geol. Surv. No. 586 (1914) p. 72.

The mineral composition of this rock, as calculated from the chemical analysis, is as follows:—

	Per cent.
Cordierite	23
Spinel	17·5
Corundum	7
Orthoclase	23
Albite	18
Anorthite	5·5
Ilmenite, apatite, etc.	6
Total...	100

This rock is remarkable for its low content of silica, combined with very high alumina. In the absence of definite knowledge of the manner of combination of iron, of lime, and of the composition of detrital chlorite, it would serve no purpose to resolve this analysis in terms of the minerals of a detrital sediment. It is necessary, however, to consider that the prime minerals were sericite and chlorite, and that kaolin, or even some free alumina, was also probably present. The low silica indicates that free

quartz, if present at all, must have been quite a subordinate constituent.

The chemical relations of this rock to the slate group are clearly established by inspection of Analyses VIII, IX, & X tabulated on p. 46. No. VIII represents Analysis V, recalculated with the addition of silica only, and its resemblance to the shale and slate analyses (IX & X) is noteworthy.

A. Renard's studies[1] of the slates of the Ardennes indicate the following variations in mineral composition :—

	Per cent.
Muscovite	38 to 40
Chlorite	6 to 18
Quartz	31 to 45
Iron-ores, rutile	4 to 7

Removal of 33 per cent. of silica from Analysis VIII gives a rock of the composition of the hornfels analysed. The close similarity in composition between VIII and X (a slate from Georgia) indicates that the corundum-cordierite-spinel hornfels is derived from a sediment of slaty type in which muscovite and chlorite dominated, and possessing little or no free silica. The Bolivar slate has been microscopically examined by T. N. Dale (*op. cit.* p. 71), and is described as constituted of muscovite, quartz, chlorite, carbonate, pyrite, magnetite, and rutile. The same conclusion as to the nature of the original rock might be gleaned from the mineral composition of the hornfels, for, with the addition of silica only, the hornfels type would be that of Class 1 : namely, an andalusite-cordierite hornfels—the typical thermal product of a normal shale or slate.

Analyses V & VII show a very striking resemblance, despite the widely different mineral compositions of the rocks.

The influence of fundamentally dissimilar physical conditions during metamorphism, on rocks of much the same composition, is brought out very clearly in the mineral-assemblages of this Scottish corundum-hornfels and the Italian chloritoid-schist.

Classes 1 (*d*), 1 (*e*), and 1 (*f*) have not been recorded from the aureole.

Class 1 (*g*) Spinel-Andalusite-Cordierite-Hornfelses.

Only two rocks of this class are recorded, both from the slopes of Creag nah Iolaire. In the one case the aluminium-silicate mineral is represented by andalusite, and in the other by sillimanite. The sillimanite-fibres are embedded in a ground-mass of cordierite, orthoclase, and spinel, with magnetite. Some plagioclase is also associated. In the andalusite type orthoclase is abundantly associated with cordierite (partly altered to a yellowish isotropic mass). The andalusite forms little prismatic crystals,

[1] Bull. Mus. Roy. Hist. Nat. Belgique, vol. iii (1882) p. 235.

or larger irregular cleaved masses, with negative elongation, in association with biotite and spinel.

Erdmannsdörffer has described a rock from Ilsethal, which must be included in Class 1 *g*. The analysis is as follows:—

XI.

SiO_2	57·16
Al_2O_3	19·18
Fe_2O_3	2·23
FeO	6·22
MgO	2·62
CaO	0·89
Na_2O	1·45
K_2O	5·72
H_2O	3·57
CO_2	0·07
TiO_2	1·18
P_2O_5	0·13
S	0·02
C	0·01
Total	100·45

XI. Cordierite-andalusite-spinel-hornfels, Ilsethal (Harz), O. H. Erdmannsdörffer, Jahrb. Preuss. Geol. Landesanst. vol. xxviii (1907) p. 136.

For the Comrie aureole a hornfels of Class 1 *g* is abnormal.

The derivation of the silica-poor hornfelses from Class 1 may be diagrammatically represented, as shown below:—

1. Andalusite-cordierite.

1 *a*. Andalusite, cordierite, corundum.
1 *b*. Cordierite, corundum.
1 *c*. Cordierite, corundum, spinel.

1 *g*. Andalusite, cordierite, spinel.
[1 *f*. Andalusite, spinel.]
[1 *e*. Andalusite, corundum, spinel.]

[1 *d*. Corundum, spinel.]

In terms of the reversible equation suggested in a previous paper,[1] the cordierite-corundum pair is the stable association in the Comrie aureole. Hornfelses 1 *a*, 1 *b*, and 1 *c* are indeed in overwhelming preponderance in the aureole, and only two of Class 1 *g* were discovered. Classes 1 *d*, 1 *e*, and 1 *f*, enclosed in square brackets, are unrepresented.

As the two abnormal hornfelses occur side by side with those of the left-hand side of the diagram, it is probable that hornfelses of Class 1 *g* are, in reality, assemblages that have not reached equilibrium. Considered as derived from Class 1, it is seen that,

[1] Geol. Mag. vol. lx (1923) p. 105.

under the pressure and temperature conditions in the Comrie aureole, andalusite is desilicated preferentially to cordierite. The question of equilibrium is further considered in a subsequent part of this paper.

Assemblages of Four Phases.

Hornfelses containing all four minerals together are found among the thermal products of the Carn Chois diorite, but only six rocks are known to me. They come from different parts of the aureole, at the contact in Daden Burn, at Tom a' Mhinn, on the slopes of Creag nah Iolaire, and from the summit of Carn Chois. They resemble the cordierite-corundum-spinel hornfelses in their petrography: but, in addition to these minerals, aluminium silicate appears either as andalusite or sillimanite. All four minerals occur together in one field of view of a 1-inch objective, and show no reaction-borders. The additional minerals are magnetite, abundant potash-felspar, and biotite. The last-named mineral may be present only in very sparing amount. It will be necessary here merely to indicate the relations of the aluminium-silicate mineral, as in other respects the description given of hornfelses of Class 1 *c* will suffice. Where this mineral is sillimanite, it occurs as long fibres, often bunched together in a sheaf-like arrangement. These prisms reach 1·5 mm. in length, and have a positive elongation: they are associated with spinel or magnetite, and set in the cordierite-base. There is no fixed orientation of these fibres, the crisscross arrangement being characteristic. (See Pl. IV. fig. 5.)

In the andalusite types the aluminium silicate is much more irregularly developed, occurring, as in Class 1 (*g*) hornfelses, in short prismatic aggregates or irregular masses. They possess the high optic axial angle of andalusite and the negative elongation.

Andalusite and sillimanite do not occur together in these rocks, as recorded by A. Lacroix,[1] R. Brauns,[2] and A. Bergeat.[3] These rocks deserve some notice from the standpoint of the phase rule, and that question will be discussed in a subsequent section of this paper.

A rock containing all four phases together has been described by Dr. J. S. Flett [4] from the Land's End granite, where it is present as an inclusion. The constituents are andalusite, cordierite, spinel, corundum, and (in addition) biotite and felspar.[5]

[1] 'Contributions à l'Étude des Gneiss à Pyroxene & des Roches à Wernérite' Paris, 1889, p. 205.

[2] Neues Jahrb. Beilage-Band xxxiv (1912) p. 111.

[3] *Ibid.* Beilage-Band xxx (1910) p. 587 & pl. xx.

[4] Mem. Geol. Surv. (Sheets 351 & 358) 1907, p. 30.

[5] This rock was originally described as containing sillimanite, in addition to the four phases above mentioned. I have been unable to confirm this determination from an examination of the slide; but Dr. Flett states that it was definitely isolated by extraction with acids.

The analysis is as follows:—

XII.	
SiO_2	47·45
Al_2O_3	27·48
Fe_2O_3	1·44
FeO	8·60
MgO	4·14
CaO	2·23
Na_2O	1·62
K_2O	2·75
H_2O +	1·97
H_2O −	0·17
TiO_2	1·26
P_2O_5	0·26
Cl, F	0·41
CoNiO	0·02
Cr_2O_3	0·02
V_2O_3	0·03
C	0·09
MnO	0·15
	100·09
Less O for F & Cl	0·17
Total	99·92

Hornfelses derivable from Class 3 of the Free-Silica Hornfelses.

In the free-silica hornfelses of Class 3, the entry of lime has resulted finally in the disappearance of andalusite, which is now represented in the anorthite member of the plagioclase. The hornfels of this type is a quartz-cordierite-plagioclase assemblage.

In the silica-poor hornfelses this class is represented by

Class 3 *a*. Cordierite, spinel, plagioclase.
Class 3 *b*. Spinel, plagioclase.

Class 3*a* hornfelses.—A typical example may be briefly described from the slopes of Creag nah Iolaire. It is a comparatively coarse-grained rock, consisting of beautifully clear and large twinned crystals of cordierite, irregular grains of magnetite, with intergrown spinel and twinned plagioclase among the cordierite-grains. This plagioclase is not always readily distinguishable from the cordierite, the twinning of which is also of the repeated type: it is, however, a coarser type of twinning. The cordierite has a grey-blue coloration in transmitted light. The plagioclase is clear and colourless, and shows a higher refraction than the cordierite. Its composition is that of a labradorite (27°). In another type biotite is present, and the cordierite is free from inclusions of associated minerals. The coarseness of grain is indicative of the high grade of metamorphism, during which the expulsion of foreign minerals has proceeded almost to completion.

Class 3 *b* hornfelses.—In this class cordierite is absent, there being insufficient silica to combine with spinel to produce this mineral. Two rocks of this type may be noticed. In the first of these a banded texture is set up by biotite-rich and biotite-poor layers. The sole colourless constituent is plagioclase, poikiloblastically enclosing octahedra of spinel. Biotite in red-brown flakes is abundant: this brown mica encloses many grains of green spinel and magnetite. The plagioclase is an acid labradorite of positive character.

In the second of these rocks the texture is much coarser, and spinel is very abundant in both the labradorite and the biotite. Of cordierite, only a few grains of its pseudomorph in parts of the section indicate its former presence. Their entry here indicates a transition to the rocks of Class 3 *a*. Rocks of Class 3 *b* are closely related to the hornfelses of Class 3, the biotite-plagioclase hornfelses described under the free-silica hornfelses.

Non-Calcic Cordierite-Spinel-Hornfelses.

We may derive from hornfelses of Class 1, Mg. i, by abstraction of silica, hornfelses of the type:

Class 1, Mg. i *a*: Cordierite, spinel.
Class 1, Mg. i *b*: Spinel.

The first of these only is met with in the Carn Chois aureole. There are, as in other hornfelses, types of these rich in biotite and types which are biotite-free, the latter being correspondingly richer in spinel and magnetite.

Cordierite is always the dominant mineral, and intergrown orthoclase often abundant. The spinel-magnetite aggregates may be quite coarse-grained. A rock from Craig More, 75 yards from the contact, is an interesting type. The original rock was a slate, and the thin section preserves the banding of the original rock completely. Linear strings, largely of magnetite, represent the original bands rich in chlorite. All biotite has been replaced by cordierite, orthoclase, magnetite, and spinel. A rock from the same contact is wholly composed of irregular ovoid crystals of cordierite, measuring 1 mm. in length, and showing the typical sieve-texture contributed by orthoclase-, spinel-, and magnetite-inclusions.

A cordierite-spinel hornfels from the slopes of Creag nah Iolaire has been analysed. The rock is a dark-grey resinous-lustred hornfels, with a high content of cordierite, the remaining constituents being felspar, spinel, small amounts of biotite, and magnetite. The spinel is enclosed in the cordierite-grains, in the form of minute green drop-like grains; but it is not in large amount.

The cordierite is pleochroic, giving weak violet tints as

Z, Y = weak violet X colourless.

The pleochroic haloes around the minute inclusions are yellow for X and colourless for Y and Z.

The alkali-felspar appears to be rather of a sanidine type than an orthoclase, for it has a distinctly low optic axial angle. Biotite is principally developed around the grains of iron-ore. Its quantitative amount does not exceed 2 per cent.

The analysis of this rock is tabulated below.

	XIII.	XIV.	XV.
SiO_2	48·35	48·88	49·91
Al_2O_3	28·29	26·14	27·49
Fe_2O_3	1·67	2·88	12·26
FeO	10·86	5·77	
MgO	3·54	2·28	0·19
CaO	1·35	0·99	0·38
Na_2O	1·84	1·12	0·73
K_2O	2·28	4·69	2·54
H_2O+	0·76	4·11	3·93
H_2O-	0·04		0·36
P_2O_5	0·05	0·11	—
CO_2	nil	—	—
TiO_2	0·60	1·55	1·23
MnO	0·34	—	0·11
NiCoO	trace	—	—
S	0·07	0·50(SO_3)	—
Totals	100·04	99·02	99·13
Specific Gravity 15°/4°	=2·744	2·82	2·95

XIII. Cordierite-spinel-hornfels, Creag nah Iolaire, Glen Lednock.[1]

XIV. Cordierite-spinel-hornfels, Diebesstieg (Harz), O. H. Erdmannsdörffer, Jahrb. Preuss. Geol. Landesanst. vol. xxviii (1907) p. 136.

XV. Chloritoid-schist, Curaglia, Graubünden (Switzerland), P. Niggli, 'Die Chloritoidschiefer des Nördostlichen Gotthard-Massives' Beitr. Geol. Karte Schweiz, n. s. pt. xxxvi (1912) p. 50.

From this analysis the percentages of the minerals in the rock are given as:—

	Per cent.
Cordierite	53
Spinel	5·5
Orthoclase	13·5
Albite	15·5
Anorthite	6·5
Biotite	2
Iron-ores, etc.	4
Total	100

It is clear that the cordierite must be comparatively rich in ferrous iron. Even if the spinel is considered as a pure hercynite, the ferrous oxide/magnesia ratio in the cordierite is approximately

[1] In view of the importance of this analysis in the discussion that follows, the constituents have been redetermined, and the ferrous oxide and ferric oxide values confirmed.

unity. Whether such a ratio represents a saturation-limit for ferrous iron in cordierites (as has been assumed by some writers) is not clear, as most of the cordierites analysed have come from rocks not excessively rich in iron. This rock, despite its lime content, is best considered under Class 1, Mg. i*a*, owing to the high ferrous iron + magnesia content. The rock is here compared with a cordierite-spinel hornfels from the Harz described by Erdmannsdörffer. The latter rock differs principally in the lower ferrous iron content and higher potash. An analysis of closer chemical resemblance is that of the four-phase assemblage hornfels cited on p. 50.

We may compare the analysis further with that of a rock which is its dynamically metamorphosed equivalent: namely, a chloritoid-schist from Switzerland, described by Niggli. In addition to chloritoid, this rock contains sericite, quartz, chlorite, iron-ores, and rutile.

Another rock of this class, but richer in spinel, comes from the contact at Craig More, Comrie. It is a fine, dark-grained, resinous hornfels. Under the microscope it is seen to be built up essentially of cordierite, spinel, iron-ores, and alkali-felspar. The texture of this rock is noteworthy. Linear strings of iron-ore and spinel run through parts of the slide, indicative of alterations of composition in the original sediment; but the most striking character is evinced by the manner of arrangement of the spinel, iron-ores, and alkali-felspar.

The analysis of this rock is as follows:—

	XVI.
SiO_2	44·52
Al_2O_3	28·63
Fe_2O_3	1·78
FeO	10·75
MgO	4·14
CaO	1·25
Na_2O	3·21
K_2O	2·69
H_2O+	0·45
H_2O-	0·20
P_2O_5	0·03
CO_2	nil
TiO_2	2·05
MnO	tr.
NiCoO	tr.
S	0·27
SO_3	tr.
Total	99·97

Mineral Composition.

	Per cent.
Cordierite	26
Spinel	15
Albite	27
Anorthite	6
Orthoclase	16
Ilmenite	4
Magnetite, pyrrhotite	6
Total	100

XVI. Cordierite-spinel-hornfels, at the contact with diorite; Craig More, Comrie.

The intricately twinned cordierite-masses have a rude porphyroblastic habit. They contain enclosed spongy aggregates of low-refracting felspar, with some iron-ore and spinel. But the

porphyroblasts themselves are separated by a network of areas in which the spinel, iron-ores, and alkali-felspar are concentrated, the main porphyroblasts being much less rich in these constituents. The origin of this texture is somewhat obscure; but it may be suggested that an attempt at clearing of the main cordierite areas from enclosed minerals is here observed, the spinel and iron-ores becoming enveloped in the more accommodating alkali-felspar, which stands lower in the graded crystalloblastic series of Becke. This rock is practically free from biotite. As the analysis given on p. 53 shows, much of the alkali-felspar must be albitic in composition, and all of it has a lower refraction than the cordierite or than Canada balsam. Pleochroic haloes surround minute zircon-grains enclosed in the cordierite.

Hornfelses derivable from Class 4 of the Free-Silica Hornfelses.

From these hornfelses we derive the following assemblages:—

Class 4 *a*. Cordierite, spinel, hypersthene, plagioclase.
Class 4 *b*. Spinel, hypersthene, plagioclase.

Representatives of both these types are found among the products of the aureole.

Class 4 *a*.—Rocks containing this assemblage are recorded from the contact at Invergeldie, and on the slopes of Creag nah Iolaire. The latter rock is of interest, as showing how closely-related types of hornfelses may be intimately associated. One part of the slide corresponds to a cordierite-spinel-plagioclase assemblage of Class 3 *a*, associated with an assemblage of Class 4 *a*, into which hypersthene enters. The pyroxene shows the characteristic pleochroism of the hypersthene of the hornfelses previously described. (See Pl. IV, fig. 3.)

A remarkable hornfels from the contact at Invergeldie deserves more detailed notice here. It is a moderately coarse-grained rock, essentially built up of plagioclase, hypersthene, spinel, magnetite, biotite, and cordierite, and merits a full description, for the hypersthene attains a size exceeding that seen elsewhere in the aureole. It is a banded rock, the individual bands corresponding in composition to Classes 4 *a* & 4 *b*: that is, bands with and without cordierite.

Hypersthene forms irregular to subidioblastic porphyroblasts up to 2 mm. in diameter. It is optically negative, with positive elongation. The pleochroism is strong, and follows the scheme

Z greyish green. Y reddish yellow. X pink.

These hypersthene-grains are filled with little octahedra of green pleonaste, showing rectangular and rhomb-shaped sections. Magnetite is similarly enclosed, and may form a core to a spinel-grain.

In the cordierite-bearing bands, the pyroxene is partly immersed in large, clear, colourless, coarsely-twinned grains of cordierite of optically negative character, in which cleavage is rarely developed.

The remaining enclosures are green spinel, magnetite, biotite, and plagioclase. Some of the cordierite is undergoing alteration to a green to greenish-yellow product, which (when alteration is complete) is almost isotropic. With incipient alteration a fine lamellation becomes apparent, and this is arranged parallel to the plane 001, as seen in idioblastic sections.

Plagioclase may be the sole colourless constituent in some bands. It is always in grains of much smaller dimensions, and is distinctly more highly refracting. It is, as a rule, multiple-twinned, and has the optical character of labradorite (28° zone perpendicular to 010).

Biotite is the most abundant mineral, developed in the characteristic red-brown flakes and enclosing spinel-grains. Apatite is an accessory. Secondary products include chlorite, white mica, and some bastitic serpentine derived from the rhombic pyroxene.

I am indebted to Mr. W. H. Herdsman, of Glasgow, for an analysis of this rock. As the mineral composition would indicate, it is a very basic type of sediment, and the analysis is noteworthy for the very low silica-percentage, combined with high ferrous iron and magnesia. The analysis, moreover, indicates that the plagioclase-bearing bands are dominant, and that cordierite forms only a small percentage of the rock. If the formula of the hornfels biotite analysed by Jannasch be adopted here, there is only sufficient silica to form hypersthene with all the residual alumina appearing in pleonaste. The biotite must, therefore, be richer in the olivine-molecule than is indicated by that analysis.

The analysis of this rock is as follows:—

	XVII.	XVIII.	XIX.
SiO_2	40·20	60·1	58·28
TiO_2	2·42	1·6	0·21
Al_2O_3	21·63	14·4	17·98
Fe_2O_3	3·13	2·1	2·42
FeO	12·29	8·2	6·52
MgO	9·17	6·1	4·88
CaO	4·25	2·8	2·01
Na_2O	1·94	1·3	1·39
K_2O	2·16	1·4	4·29
H_2O-	0·33	1·4	2·19
H_2O+	1·78		
P_2O_5	0·06	—	0·07
(CoNi)O	tr.	—	—
MnO	0·35	—	0·17
S	0·18	—	—
SO_3	0·17	—	—
CO_2	tr.	—	—
Totals	100·06	99·4	100·41

Specific gravity 16°/4° = 3·015.

XVII. Spinel-hypersthene-plagioclase-cordierite-hornfels; Invergeldie Burn, Glen Lednock.

XVIII. Analysis recalculated with the addition of silica.

XIX. Hornfels of Class 4; essexite-contact. Sölvsberget (Norway). V. M. Goldschmidt, Vid. Selsk. Skrifter (1911) No. 1, p. 162.

The biotite being estimated as forming approximately 30 per cent. of the rock, the mineral composition is computed as follows:—

	Per cent.
Biotite	28
Anorthite	21
Albite	16
Hypersthene	14
Cordierite	6
Spinel	7
Iron-ore	8
Total	100

The hornfels biotite analysed by P. E. Jannasch[1] corresponds to a formula

$$H_4K_2Al_4Si_4O_{17}\,.\,3(MgFe)_2SiO_4,$$

and the calculated composition of the biotite in this rock is close to

$$H_4K_2Al_4Si_4O_{17}\,.\,4(MgFe)_2SiO_4.$$

It is of interest to compare the analysis of this rock with that of a corresponding free-silica hornfels. For this purpose the analysis has been recalculated with the addition of silica, to conform to the silica-percentage of a hornfels of Class 4, described by Dr. V. M. Goldschmidt from the essexite-contact of Sölvsberget.

It is clear that we may derive from the non-calcic free-silica hypersthene-hornfelses, by abstraction of silica, such types as the classes

1, Mg ii (*a*) Hypersthene, cordierite, spinel, biotite.
1, Mg ii (*b*) Hypersthene, spinel, biotite.

None of these types are, however, recorded from this area, the hypersthene types being relegated to those in which plagioclase plays a prominent part.

Accessory Minerals in the Hornfelses.

Titanium-bearing minerals.—Rutile is not an infrequent accessory of the rocks outside the aureole, especially in the argillaceous types. It is, however, much less common in the hornfelses derived from these rocks, and for the greater part the titanium appears in other minerals.

In the biotite-free types of these argillaceous hornfelses, both free-silica and silica-poor members, titanium oxide is combined with ferrous oxide in ilmenite, which is readily recognized by its habit and manner of alteration. This applies also to the biotite-bearing varieties; but here it is clear that some of the titanium is absorbed into the biotite-molecule, analyses of which may show quite considerable amounts of this constituent.

The chlorite of the metamorphosed rocks may show rutile-needles enclosed within them, these being thrown out in the

[1] Nyt Mag. f. Naturv. vol. xxx (1886) p. 318.

decomposition of the biotite from which the chlorite is originally derived. Some of this rutile is reabsorbed into the newly formed biotite in the hornfels zone. That these biotites do contain titanium is very clearly indicated by a similar production of rutile, when they are again secondarily changed to chlorite, the rutile-needles forming a sagenitic web in the chlorite pseudomorph.

This mode of development of titanium is followed in the hornfelses of the classes richer in lime, as in the derivatives of Classes 3, 4, & 5. In Class 7, however, titanium appears in titanite, and this mineral is also noted in the epidote-hornfelses.

In less lime-rich types titanite only occurs where the metamorphism is incomplete, or in some of the sandstone-hornfelses, where it is apparently recrystallized from detrital sphene in a quartzose matrix.

Apatite is common to all the hornfelses, occurring in long needles with hexagonal cross-sections. Zircon likewise has a uniform distribution, and is the more readily recognized when it is enclosed in biotite or cordierite, so as to give the characteristic pleochroic haloes.

Tourmaline is present in the hornfelses, both as a detrital constituent and as a pneumatolytic product. The detrital tourmaline very readily recrystallizes, and is of the common green-brown tint. Tourmaline of pneumatolytic origin is found only close to the contact, as at Creag nah Iolaire, where it forms radiating prisms developed along joints and fissures in the hornfelses.

Pyrrhotite and pyrite are commonly met with in the argillaceous hornfelses. They are present in these rocks, both in isolated grains and in thin parallel streaks traversing the hornfelses.

X. Mineralogical Changes in Metamorphism.

Having now considered the classification of the various hornfelses and the progressive changes which are observed to take place from the outer limits of the aureole to the contact, I propose to consider the conditions of genesis of these products from the standpoint of the original minerals in the rocks subjected to metamorphism.

In any application of the phase rule to mineral-assemblages we arrive only at the possible mineral associations, the maximum number found together being limited at equilibrium; but the phase rule gives no information as to the particular mineral associations. I have attempted to indicate what these mineral-assemblages are, and their production can be represented by a set of ideal equations, which, be it observed, are not those likely to have operated during metamorphism in the rocks.

The mechanism of the actual reactions is in many cases obscure; but an attempt to determine some of the dominant rearrangements

Hornfelses of the Inner Contact-Zone of the Carn Chois Diorite.

Shale-Calcic Group. (Free-Silica Hornfelses.)	Shale-Calcic Group. (Silica-poor Derivatives.)	Non-Calcic Hornfelses. (Free-Silica and Silica-poor Types.)	
(1) Andalusite, cordierite.	1 *a*. Andalusite, cordierite, corundum.		
	1 *b*. Cordierite, corundum.		
	1 *c*. Cordierite, corundum, spinel.		
	1 *d*. [Corundum, spinel.]	1, Mg. i. Cordierite.	1, Mg. ii. Cordierite, hypersthene.
(2) Andalusite, cordierite, plagioclase.	1 *e*. [Corundum, spinel, andalusite.]	↓	↓
	1 *f*. [Spinel, andalusite.]		
	1 *g*. Spinel, andalusite, cordierite.	1, Mg. i *a*. Cordierite, spinel.	1, Mg. ii *a*. [Cordierite, hypersthene, spinel.]
(3) Cordierite, plagioclase.		1, Mg. i *b*. [Spinel.]	1, Mg. ii *b*. [Spinel, hypersthene.]
	3 *a*. Cordierite, spinel, plagioclase.		
	3 *b*. Spinel, plagioclase.		
(4) Cordierite, plagioclase, hypersthene.	4 *a*. Cordierite, spinel, plagioclase, hypersthene.		
	4 *b*. Spinel, plagioclase, hypersthene.		
(5) Plagioclase, hypersthene.			
(6) [Hypersthene, plagioclase, diopside.]			
(7) Diopside, plagioclase.			

Biotite and orthoclase may be present in all the above assemblages as additional minerals.

will here not be out of place, and may serve as a comparison with the preceding section where the assemblages were ideally derived.

This part of the subject is one frequently passed over without comment in memoirs on contact-metamorphism, and the reader is supplied with a mere mass of descriptive data, without any serious attempt to explain the conditions of genesis.

The prime minerals that have taken part in the various reactions by which an ultimate recrystallized hornfels is formed are those of the slates and grits: namely, quartz, chlorite, sericite, perhaps some kaolin, iron-ores, hæmatite, limonite, rutile, and calcite. The most important of these are the first three (quartz, chlorite, and sericite).

We may now consider the changes as they occur in progression. As noted above, the first sign of definite chemical change as the outer border of the aureole is entered is—whether in the Aberfoyle Slate-band or in the Ben Ledi Grits—the production of tiny flakes of brown mica amid the sericite-chlorite mass of the original rock.

In this respect the changes noted here differ from the changes in certain other aureoles, where spotting begins with a clear chemical change in the production of ill-developed spots of andalusite or cordierite, thus preceding the development of biotite.

Now, in the outer zone of the aureole in the slates, neither andalusite nor cordierite is recorded, these minerals making their appearance only in the true zone of hornfelses: in fact, andalusite is a comparatively rare metamorphic mineral of the aureole as a whole.

The absence of both of these minerals in the early stages of metamorphism finds an explanation in the general absence of kaolin as a constituent of the unaltered rocks. Where andalusite occurs in other aureoles at this stage, kaolin or a similar hydrated substance can be discovered in the original rocks; and, indeed, its presence may often be postulated from the results of analysis, there being insufficient potash to combine with alumina to form white mica.

Thus, in those rocks in which kaolin is abundant, the first changes are of the type

$$(a)\quad H_4Al_2Si_2O_9 \rightarrow Al_2SiO_5 + SiO_2 + 2H_2O;$$

$$(b)\quad \underset{\text{(kaolin)}}{8H_4Al_2Si_2O_9} + \underset{\text{(chlorite)}}{2H_8Mg_5Al_2Si_3O_{18}} + 3SiO_2 = \underset{\text{(cordierite).}}{5Mg_2Al_4Si_5O_{18}} + 24H_2O$$

The production of biotite from chlorite and white mica is a change not easily represented. It is frequently to be observed that this very readily takes place where grains of iron-ore are enclosed in these matrices. This change may be represented as

$$K_2H_4Al_6Si_6O_{24} + 6FeO + 3SiO_2 = \left\{ \begin{matrix} K_2H_4Al_6Si_6O_{24} \\ 3Fe_2SiO_4 \end{matrix} \right\}.$$

If the brown mica formed by the reaction of chlorite and white

mica conforms to the usual composition limits, it may perhaps arise from reaction of the sericite and the serpentine-molecule of chlorite, thus

$$K_2H_4Al_6Si_6O_{24} + 2H_4Mg_3Si_2O_9 = \left\{ \begin{matrix} K_2H_4Al_6Si_6O_{24} \\ 3Mg_2SiO_4 \end{matrix} \right\} + SiO_2 + 4H_2O,$$

the original chlorite being enriched in the amesite-molecule.

As metamorphism advances, the biotite-flakes increase both in size and in number, until recrystallization of the whole rock begins with the disappearance of both chlorite and sericite, and the incoming of cordierite and other minerals typical of the inner zone of hornfelses. Cordierite does not arise in these rocks from one type of reaction alone, and it is probable that at least three modes of genesis can be defined. Nor, on the other hand, does biotite arise solely by the reactions illustrated above.

The next stage of change occurs where cordierite and biotite arise simultaneously by a reaction of the type

$$4K_2H_4Al_6Si_6O_{24} + 6H_8Mg_5Al_2Si_3O_{18} + 9SiO_2 = 4\left\{ \begin{matrix} K_2H_4Al_6Si_6O_{24} \\ 3Mg_2SiO_4 \end{matrix} \right\} + 3Mg_2Al_4Si_5O_{18} + 24H_2O.$$

Even in these reactions iron-oxides play a part, for the biotites of contact-rocks contain a high percentage of ferrous iron, higher than in the original chlorites.

When the rock is completely recrystallized, potash-felspar is often a prominent constituent. Two sources of this mineral are available:—

(1) Sericite.

$$K_2H_4Al_6Si_6O_{24} + 2SiO_2 = 2KAlSi_3O_8 + 2Al_2SiO_5 + 2H_2O\,;$$

so that in the sericite-rich members, provided sufficient silica be available, orthoclase and andalusite occur together; if, however, much chlorite was originally present, andalusite does not appear, being utilized in the production of cordierite.

(2) Biotite.—Some potash-felspar is derived at the expense of biotite. This action is especially dominant in the highest grades of metamorphism:—

$$\left\{ \begin{matrix} K_2H_4Al_6Si_6O_{24} \\ 3Mg_2SiO_4 \end{matrix} \right\} + 12SiO_2 + 2K_2H_4Al_6Si_6O_{24} = 3Mg_2Al_4Si_5O_{18} + 6KAlSi_3O_8 + 6H_2O,$$

or, again,

3 biotite + 6 quartz = 6 orthoclase + 3 cordierite + 4 magnetite.

This latter reaction is a type characteristic of the highest grades, where the biotite is very rich in ferrous oxide. The evidence for

reactions of this type is very strong, and has been sufficiently emphasized in the preceding petrographical description (see pp. 37 & 44).

In the absence of free quartz, corundum arises in rocks comparatively rich in sericite, by a reaction producing, in addition, potash-felspar:—

$$K_2H_4Al_6Si_6O_{24} = 2Al_2O_3 + 2KAlSi_3O_8 + 2\,H_2O.$$

That this is a leading reaction in the production of corundum is proved by the frequent association of these two minerals, corundum idioblasts being embedded in a granular matrix of orthoclase.

I can now indicate in tabular form the assemblages which arise from mixtures of sericite, chlorite, and quartz, when present together in varying proportions. In dealing with this problem considerable light is thrown on their manner of genesis from the products which arise from these minerals, when they are subject to high temperatures at ordinary pressures. Thus, among the products of fusion of muscovite is corundum, and of normal chlorite olivine and spinel.

Sericite-chlorite mixtures.—From rocks largely constituted of these minerals we may expect, according to the proportions, corundum, spinel, cordierite, or hypersthene. Thus, pure sericite can give rise to orthoclase and corundum, as in the equation set forth above, and a chlorite composed of equal parts of the serpentine-molecule and the amesite-molecule can give rise to olivine, enstatite, and spinel: thus

$$H_8Mg_5Al_2Si_3O_{18} = Mg_2SiO_4 + 2MgSiO_3 + MgAl_2O_4 + 4H_2O.$$

Then mixtures of sericite and chlorite give the following:—orthoclase, olivine, enstatite, spinel, and corundum.

But there are obviously reactions entering here which inhibit the presence of olivine: it is absorbed by the muscovite-molecule to give biotite. Furthermore, corundum and enstatite do not occur together, but in their place arise spinel and cordierite. The ideal reaction would be

$$5MgSiO_3 + 5Al_2O_3 = Mg_2Al_4Si_5O_{18} + 3MgAl_2O_4.$$

Thus, with sericite-rich members of chlorite-sericite mixtures, all the enstatite and olivine are removed, and our typical hornfels then becomes an assemblage of cordierite, spinel, corundum, biotite, and orthoclase. This is the hornfels of Class 1 *c*.

It is clearly indicated here that there is no reason to postulate free alumina in the sediment, as bauxite or laterite, to account for the occurrence of spinel and corundum in these hornfelses.

In the mixtures richer in chlorite a stage will be reached at which all corundum is used up in converting enstatite to spinel and cordierite, and so we derive assemblages of cordierite, spinel, biotite, and orthoclase. This is the hornfels of Class 1, Mg. i *a*.

Again, in chlorite-rich members more potential olivine will arise than can be absorbed by sericite to give the biotite-molecule. Another reaction, however, inhibits its presence: for cordierite and forsterite do not occur together, and in their place arise spinel and enstatite, thus:—

$$Mg_2Al_4Si_5O_{18} + 5Mg_2SiO_4 = 2MgAl_2O_4 + 10MgSiO_3.$$

We thus arrive by gradual increments of chlorite in the original rock to an assemblage of cordierite, spinel, enstatite, biotite, and orthoclase. This assemblage is the hornfels of Class 1, Mg. ii *a*.

In our silica-poor hornfelses mixtures of this richness in chlorite are not reached: for our cordierite-spinel-enstatite assemblages contain plagioclase, and belong to Class 4 *a*.

HORNFELSES OF SERICITE-CHLORITE ROCKS.

i. Orthoclase, corundum.
ii. Orthoclase, corundum, cordierite, spinel, biotite.
iii. Orthoclase, cordierite, spinel, biotite.
iv. Orthoclase, cordierite, spinel, enstatite, biotite.

If now, quartz be added to the original rocks, the classification is extended, as in the following table:—

HORNFELSES OF SERICITE-CHLORITE-QUARTZ ROCKS.

Sericite. ——→ Increasing quartz ——→

Increasing chlorite ↓			
	Orthoclase, corundum.	Orthoclase, andalusite, corundum.	Orthoclase, andalusite, quartz.
	Orthoclase, cordierite, corundum, spinel, biotite.	i. Orthoclase, andalusite, corundum, cordierite. ii. Orthoclase, cordierite, corundum, biotite, and others.	Orthoclase, andalusite, cordierite, quartz, biotite.
	Orthoclase, cordierite, spinel, biotite.	Orthoclase, cordierite, biotite.	Orthoclase. cordierite, quartz, biotite.
	Orthoclase, cordierite. spinel, enstatite, biotite.	Orthoclase, cordierite, enstatite, biotite.	Orthoclase, cordierite, enstatite, quartz, biotite.

On comparison of these assemblages with those described, it will be seen that they represent the classes already established.

XI. Rock-Textures of the Hornfels Zone.

The variety of texture shown by the contact-rocks of the aureole is not wide, but such as there is may be conveniently noted together in this section. We may distinguish porphyroblastic types, such as the hornfelses of Class 1 & 1 *a*, in which the andalusite forms sharply bounded prisms with only a few inclusions of magnetite and biotite in a fine-grained ground-mass. Hypersthene may also appear in this manner, as in the hornfels of Class 4 *a* & 4 *b*: here the hypersthene encloses numerous grains of spinel and magnetite.

The typical hornfels texture in which the various phases possess a crystallizing force of the same order (that is, minerals which appear close together in the order of the crystalloblastic series) is characteristically illustrated by hornfelses of Class 3 or Class 1 Mg. i,' in which cordierite, orthoclase, quartz, and plagioclase are closely associated and intergrown.

Sieve-texture is common here, as well as in other hornfelses. Thus, cordierite may form comparatively large spreading plates or irregularly bounded crystals (often multiple twinned) enclosing the other constituents of the ground-mass—such as biotite, spinel, quartz, or orthoclase. Spinel is the enclosed mineral in the silica-poor hornfelses of Class 1.

In the free-silica hornfelses, however, both quartz and orthoclase may appear as hosts for numerous cordierite or plagioclase-granules. In the hornfelses of Class 7, for example, the plagioclase is partly enclosed in quartz or orthoclase-plates in this manner, and orthoclase acts in a similar way for cordierite-granules in the hornfelses of Class 4.

The mode of development of plagioclase just described is entirely different from that in the silica-poor hornfelses, such as the biotite-plagioclase hornfelses and the plagioclase-bearing hornfelses of Classes 3 *a* & 4 *a*. Here the plagioclase forms idioblasts of tabular habit or equigranular grains, between which enter plates of biotite. Where quartz is abundant, however, it appears often capable of enclosing other minerals in the manner described above, and the same remark may also apply to orthoclase.

XII. Size of Grain of the Rocks of the Hornfels Zone.

In general, the coarsest type of hornfelses occur at the actual contact with the igneous rock. The best examples of such coarse-grained hornfelses occur at Invergeldie. On the slopes of Creag nah Iolaire beautiful fluor-violet hornfelses of coarse texture contain idioblastic cordierite-grains measuring up to 2 mm. in diameter. A hornfels from this locality has been described (Class 3 *a*). In these coarse-grained cordierite-rocks, this mineral is often remarkably free from inclusions. This is doubtless directly connected with the grade of metamorphism, the rejection of inclusions being increasingly facilitated as the grade of meta-

morphism advances. The sediment at the contact is maintained at a high temperature for longer periods than the rocks in the outer part of the hornfels zone, again facilitating an increase in size of grain. Experimental confirmation of this is given by the work on dry melts, and the studies of F. Rinne[1] on 'Sammelkristallisation'.

Coarse hornfelses rich in biotite are found at the Invergeldie Burn contact, north of Invergeldie. Here the biotite-plates reach a diameter of 3/8 inch.

While it is true that the coarsest hornfelses are found at the immediate contact, yet fine-grained hornfelses are also abundant at the same points. Some hornfelses of Class 3 & Class 1 Mg. i, are witness to this fact. Moreover, the composition of these is such that we must suppose that they were originally of the same order of grain-size before metamorphism as the sediments from which the hornfelses already described were produced: therefore, neither difference in original size of grain nor difference of composition can account for these anomalies.

Relation to original size of grain.—There is, however, a distinct relation between the present size of grain and the original size in many of the sandstone-hornfelses. The original quartz- and felspar-pebbles in the grits are often preserved in the highest grades. Even here, however, we may note the prevailing tendency of metamorphism to destroy the original inequality in size of grain between the pebble and its matrix.

The large grains tend to become broken up into smaller grains of diverse orientation, and the gradual disappearance of the strain-shadows of the original grains is some measure of the accompanying recrystallization. In favourable circumstances the evidence of original inequality in size of grain may be traced only in the heterogeneity in composition of the hornfels.

Banding in hornfelses.—Hornfelses of two or even more classes associated together within the limits of a microscopic thin section are not infrequently encountered. Most commonly neighbouring bands comprise hornfelses of adjacent classes: for example, the described rock showing an association of hornfelses of Classes 3 & 5. A more remarkable example is an epidote-hornfels, with thin interbands of argillaceous composition, containing spinel and plagioclase.

Banding, on the other hand, may arise from unequal distribution of a given mineral. The minerals which set up banding in this way are principally biotite, magnetite, and spinel. Thus, biotite may occur in linear clusters between comparatively biotite-poor areas; or linear clusters of magnetite alone, or combined with spinel, may play a similar part. Banding of this type, or of the more general type described above, must be set down to original

[1] Min. Petr. Mitth. vol. xxvii (1908) p. 395.

heterogeneity in the sediment, and affords eloquent testimony regarding the strictly limited radius of diffusion in metamorphism.

Some of the most remarkable banded hornfelses are found on the southern slopes of Creag nah Iolaire, east of Invergeldie, and it is at this locality that the coarsest hornfelses occur. Practically all the recognized types of cordierite-hornfelses can be obtained from this locality. On weathered surfaces the banding of these hornfelses is very evident. Some of the narrow bands consist almost wholly of cordierite, which, owing to its resistant weathering, forms linear excrescences on the smooth surface of the rock. The contrast between the bands is further emphasized by the lilac or fluor-violet tint of the cordierite-rich layers as compared with the grey or white weathering of the less cordierite-rich bands.

XIII. Metamorphism of Igneous Rocks in the Carn Chois Aureole.

Outside the aureole of the Carn Chois diorite, the sills and sheets of epidiorite which form part of the Dalradian System are in this neighbourhood made up essentially of hornblende, plagioclase (either albite or oligoclase), zoisite, epidote, chlorite, and sphene. A little quartz, iron-ore, apatite, and biotite may also be present.

These rocks represent dynamically metamorphosed gabbros or dolerites. The original pyroxene is now replaced by hornblende with chlorite, and the plagioclase by albite and an epidote-mineral (either zoisite or epidote itself). Some of the sphene represents original ilmenite, as is indicated by its habit; and some is doubtless derived as a bye-product of the pyroxene-amphibole conversion.

These are the essential characters of the epidiorites of the Glen Lednock area. The changes that these rocks undergo when they become involved in the thermal aureole can be well studied in the epidiorite-sheet that is invaded by the diorite near Spout Rolla, west of Invergeldie. The rocks take on rapidly a hardened hornfelsic aspect, following partial or complete reconstitution.

The early changes consist in the development of magnetite crowding the hornblende-crystals, the recrystallization of small hornblende-crystals in the base, and the production of brown mica, especially in the vicinity of magnetite. At the same time, zoisite and epidote begin to disappear, and the same remark applies to sphene. These changes result in the production of more basic felspar, the albite and zoisite reacting to give a more calcic plagioclase.

Closer to the contact, the changes are still more fundamental, and pyroxenes arise in place of amphibole.[1]

[1] Garnet has been found in one of these metamorphosed epidiorites. Its associated minerals (pyroxene and calcite) are a good index of its nature: to wit, grossularite, and it is probable that the association is the metamorphic product of a calcareous vein in the original epidiorite.

The ultimate product of this metamorphism is a granular pyroxene-hornfels, in which some hornblende is still preserved.

An example from the contact at Spout Rolla may here be noticed. This rock has lost all the macroscopic characters of the somewhat foliated epidiorite outside the aureole. Relict grains of fibrous uralite are, however, still shown in thin section; but the rock is now a dark-grey hornfels. The constituents are hornblende, diopsidic pyroxene, hypersthene, plagioclase, biotite, and iron-ores.

Hornblende is present in large grains as in the original rock, and as granules in the felspar ground-mass, but these show various stages of conversion to pyroxenes, with which is associated magnetite. Diopside is recognized by its high double-refraction, wide extinction-angle, and the absence of pleochroism. The associated hypersthene, on the other hand, shows the typical pink-green pleochroism, low birefringence, and straight extinction. Ultimately, the original hornblende-grains may be almost completely transformed into an aggregate of the two pyroxenes. Biotite is typically developed around grains of iron-ore. The hornfelsic character of the rock is, however, largely imparted by the equigranular, almost pflaster texture of the felspar: this has the composition of labradorite. The titanium in the original epidiorite must now be largely distributed between the iron-ore, biotite, and pyroxene. The change of amphibole to a mixture of the two pyroxenes is that naturally expected under high-temperature conditions, and is clearly a transformation of the type

$$CaMg_3Si_4O_{12} = CaMgSi_2O_6 + 2MgSiO_3.$$

This rock shows very clearly an approach to the mineralogical composition of sedimentary hornfelses of Class 6: namely, hypersthene-diopside-plagioclase; and, if the hornblende had been completely transformed into pyroxenes, the resemblance would be very striking. The quantitative proportions of the various minerals, however, are different, and this is revealed by chemical analyses of such rocks. It is, nevertheless, quite clear that the mineralogical composition of a reconstituted hornfels is independent of the original mineral composition: for, as this rock shows, in the one case the original type was of igneous origin, and in the other a calcareous shale.

XIV. The Condition of Equilibrium in the Inner Zone of Hornfelses.

The measure of success with which the phase rule can be applied to mineralogical assemblages in rock-metamorphism, and the utility of an ideal classification of metamorphosed sediments developed with its aid, must of necessity largely depend on the approach towards equilibrium condition of the final products.

In subjecting mineral-assemblages to the test, it seems hardly necessary to emphasize that—where discernible—secondary minerals must be ruled out, that only those minerals which come

within a common sphere of diffusion must be considered. Yet we find repeatedly in descriptions of rocks that mere lists of minerals are given, often without any indication of important mineral associations. Not all the minerals observed in a rock-slice can always be considered as part of one reacting system, for some of them may be protected from interaction by a barrier imposed by others, the range of diffusion being quite limited. Thus spinel and quartz, as also corundum and quartz, may appear in the same thin section, but are never observed in actual contact, yet petrological descriptions abound, in which no comment is made on unusual combinations, the reader being left in doubt as to the actual association. The importance of these considerations from the genetic standpoint can scarcely be overestimated. If the rock be not considered rigidly from the standpoint of the primary reacting system, it is easy to see that a false idea of the degree of approach towards equilibrium to which the rock has attained will be given. The mineral assemblages of accidental xenoliths, where the reacting system is brought into contact with foreign liquid (magmatic solutions), represent a complex system in which equilibrium is often not likely to be attained. Sufficient time has not permitted the system to react as a single unit, and such assemblages can frankly be considered as unstable, to be excluded from the general case of rocks of the inner zone of hornfelses, such as we are considering here. Excellent examples of the case just given are illustrated in the pyrometamorphic rocks of Brauns [1] from the Laacher See district of the Eifel, and in the xenolithic masses in the tholeiite intrusions of Mull, as described by Dr. Herbert H. Thomas.[2] But such examples are of great interest and importance, as indicating the direction in which the approach towards equilibrium is tending, and throw light on the genesis of other assemblages.

The products of outer zones of thermal aureoles must also be excluded, and it should be obvious that the equilibrium condition is unlikely to be attained in those cases where only the reactions most susceptible to a rise of temperature have progressed.

The ideal classification of hornfelses must confine itself to the inner zone of hornfelses, where the whole rock is reconstituted and recrystallized. With this understanding the condition of equilibrium may be examined. The mineral assemblages as now revealed are those presumably arising under the condition of the highest temperatures attained, to which the particular system was exposed. The existence of this assemblage at ordinary temperatures indicates that, during the cooling of the rock, the chemical reactions appropriate to lower temperatures did not proceed to any marked extent. The equilibrium, or approach thereto, is therefore that of the highest temperature. The difficulties would be of less moment

[1] R. Brauns, 'Die Kristallinen Schiefer des Laacher See-Gebietes & ihre Umwandlung zu Sanidinit' Stuttgart, 1911.

[2] Q. J. G. S. vol. lxxviii (1922) p. 229.

if these ideal conditions were always realized; but, unfortunately, the system does not always remain non-reacting on the cooling curve. This is clearly the case (to take one example only) in certain amphibole-hornfelses, where an original pyroxenic hornfels is partly or wholly converted to an amphibole type. The condition of the reacting system may thus be in part changed during its later history, and these subsequent changes may not always be discernible by examination of thin sections. Under these conditions, the number of phases represented in the system may well exceed the number of components, even if we assume that at the highest temperatures the rock-unit had reached equilibrium.

Dr. A. Harker[1] has observed that the comparative rarity of zoned crystals in metamorphosed rocks suggests that equilibrium is more promptly attained, or more closely approached, than in a crystallizing magma. The same conclusion might be reached from the consideration that in the metamorphosed rock the system reacts, and is adjusted to the conditions of elevation of temperature; whereas in the igneous rock it responds to a falling temperature, where the 'lag effect' is much greater.

These considerations apart, however, the fact that equilibrium is very frequently attained in the inner zone appears to be indicated by the success with which the hornfelses can be partitioned in some ordered scheme, as represented in the classification adopted above. Exceptions must be admitted, carefully noted, and considered. In the present incomplete state of our knowledge of the constitution of certain of the mineral phases, there must be often some difficulty in determining or inferring (guessing, as J. Johnston & P. Niggli[2] would have it, with certain rocks) the number of components; and, with a lax inference, it would be possible to indicate most rocks as conforming to the phase rule. It is here that caution is particularly necessary.

We may now return to the consideration of specific hornfelses as a test of complete attainment of the equilibrium condition. In dealing with the various assemblages of the corundum- and spinel-hornfelses, a number of abnormal types were described, containing four phases: namely, the corundum-spinel-cordierite-Al_2SiO_5 associations referred to on p. 49. The four- (or possibly five-) phase assemblage described by Dr. J. S. Flett[3] may also be noted here, an analysis of which is quoted on p. 50. Rocks of this type can only be considered as having reached equilibrium if magnesia and ferrous oxide are treated as independent components. The justification of such an assumption is, however, not evident to the present writer.

The crucial point is disclosed in the composition of the cordierite phase. To what limit is the replacement of magnesia by ferrous

[1] Q. J. G. S. vol. lxxiv (1918) p. lxviii.
[2] Journ. Geol. vol. xxi (1913) p. 589.
[3] Mem. Geol. Surv. (Sheets 351 & 358) 1907, p. 30.

oxide in the cordierite possible in systems developed under the conditions of pressure and temperature prevalent in thermal aureoles? Their separation is justifiable, only if in the rocks concerned the cordierite is saturated, or has reached the maximum possible ferrous oxide/magnesia ratio, if indeed pure iron-cordierites are incapable of existence.

The simple mineralogical composition of the analysed rock tabulated on p. 52 enables one to show that the cordierite must at least possess a ferrous oxide/magnesia ratio of unity, and so the saturation-limit cannot be below this value. In thin section, the cordierite betrays its high iron-content by marked pleochroism (see p. 51).

Moreover, if H. Bücking's analysis be correct, much higher contents of ferrous oxide in cordierite are possible (Neues Jahrb. vol. ii, 1901, Referate, p. 72).

Now, the cordierites of the four-phase assemblages from the Carn Chois aureole do not show the pleochroism in thin section of those of the analysed rock, and there is no warrant to assume that they are saturated. The same point is brought out by exâmination of the Cornish hornfels, and its analysis. In this rock there is no trace of pleochroism or colour in the cordierite, and the accompanying spinel is a very pale-green type, much less strongly coloured than the spinel of the analysed Comrie rock. In the light of these facts, the conclusion is reached that the four-phase assemblages have not attained equilibrium, and, if Dr. Flett's contention that andalusite and sillimanite are found together in the Cornish hornfels be correct, the departure from equilibrium conditions is still greater, for these two minerals must be treated as separate and distinct phases. Andalusite and sillimanite are not recorded from one and the same rock in the Comrie hornfelses; but assemblages such as corundum-cordierite-spinel-andalusite and corundum-cordierite-spinel-sillimanite may be found close together in the field, as at Creag nah Iolaire. It is difficult to believe that this close association is connected with temperature distribution, and no clear explanation is forthcoming, unless some resort is had to W. Ostwald's law of successive reaction, in which equilibrium is finally approached by passage states through metastable forms.

The occurrence of these hornfelses in thermal aureoles, however, does not in my view invalidate the use of the classification adopted for the rocks of the hornfels zone, but serves to indicate that equilibrium in the inner zone of hornfelses is closely approached, rather than completely attained.

In conclusion, I wish to record my indebtedness to Dr. A. Harker for encouragement and advice during the progress of these studies; to Dr. J. S. Flett for helpful criticism; and to Mr. J. M. Wordie for the free use of his collection of rocks and slides from this area.

EXPLANATION OF PLATE IV.

[All the figures are magnified 31 diameters.]

Fig. 1. Hornfels of Class 7 (diopside-plagioclase-hornfels). The constituents are diopside and biotite, enclosed in a base of quartz, orthoclase, and plagioclase, the last-named appearing as granules in the quartz and orthoclase. (See p. 35.)

2. Hornfels of Class 1 Mg. i (cordierite-hornfels). The constituents are cordierite, biotite, quartz, and orthoclase. The cordierite is present partly as granules within quartz-grains. (See pp. 36–37.)

3. Hornfels of Class 4 *a* (cordierite-hypersthene-spinel-plagioclase). Hypersthene with numerous octahedra of spinel in a base of twinned cordierite enclosing plagioclase and spinel. (See p. 54.)

4. Hornfels of Class 1 Mg. ii (cordierite-hypersthene-hornfels). The numerous grains of hypersthene appear in a colourless base of cordierite and orthoclase with magnetite. (See p. 38.)

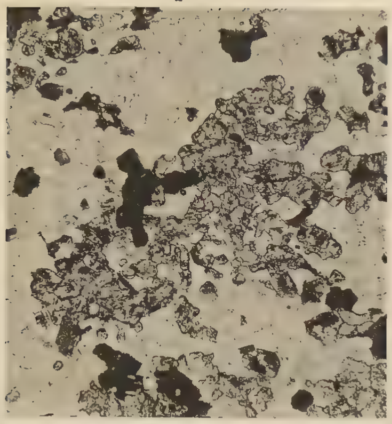
5. Corundum-cordierite-spinel-sillimanite-hornfels. Large corundum-grains in a base of cordierite and orthoclase. On the left sillimanite, which is also present in needles in the cordierite. Spinel-grains appear dark. (See p. 49.)

Discussion.

Dr. Alfred Harker congratulated the Author upon a valuable contribution to British Petrology, embodying the most comprehensive study of a metamorphic aureole hitherto made in the Highland region. The rocks described included an unusually wide range of variety. Of special interest were the hypersthene-bearing types, the banded rocks rich in cordierite, apparently of a notably ferriferous kind, and the quartzless hornfelses characterized by corundum and spinel: all these rocks belonged to types little known in Britain.

Dr. L. L. Fermor said that he was greatly interested in the paper, and especially in the Author's deduction from analyses that the cordierite present in some of these rocks contained an abnormally high proportion of iron, the ferrous oxide/magnesia ratio being as high as 1 : 1. He thought, therefore, that he might appropriately mention a curious series of rocks formed on the Indian coalfields by the melting at the outcrop of shales (and sandstones) overlying coal-seams, when the latter caught fire. The rocks thus formed had been completely melted, and usually showed the vesicular and flow-structures so often seen in true lavas: on account of this similarity, and the fact that these sediments had been completely melted at the surface, the speaker had referred elsewhere to the resultant rocks as para-lavas. Under the microscope they normally showed a glassy matrix, with abundant phenocrysts of a variety of minerals, among which mention might be made of cordierite, sillimanite, enstatite, plagioclase, and an iron-ore. The cordierite-crystals were pseudo-hexagonal in crystallization, showing the normal interpenetration-twinning; this is noticed at once without the nicols being crossed, on account of the strong pleochroism of the mineral, which is violet in thin sections. A quantitative analysis of a specimen of rock containing this

1



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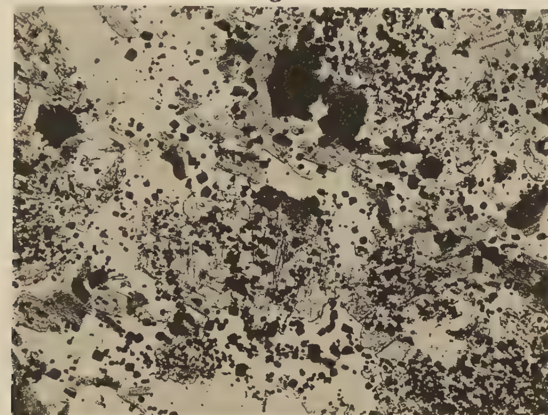

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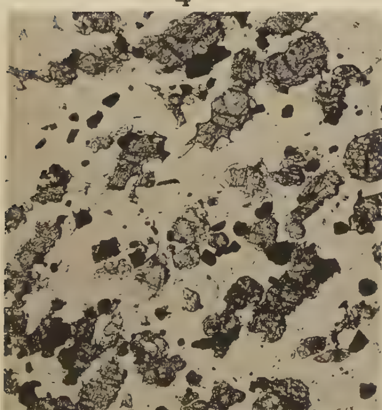

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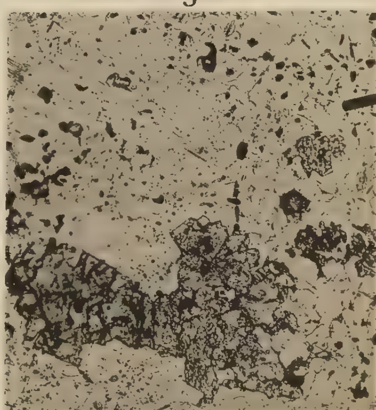


HORNFELSES from the COMRIE DISTRICT (PERTHSHIRE).

cordierite showed the presence of so small an amount of magnesia that it is necessary to deduce that there must be an iron-cordierite almost devoid of magnesia. The Scottish cordierite, with a ferrous oxide/magnesia ratio of 1 : 1, is faintly violet in thin section, and the Indian cordierite, with very little magnesia, is strongly so. From this it appears to follow that the violet colour of cordierite depends upon its iron-content.

It is interesting to note that the rocks described by the Author have been formed from argillaceous sediments by regional metamorphism followed by contact-metamorphism, while the Indian para-lavas have been formed direct from argillaceous sediments by direct fusion at surface-pressures.

The Author expressed his thanks for the kind reception of the paper. It was of great interest to hear of Dr. Fermor's discovery of cordierites so rich in ferrous oxide. The existence of such cordierites very strongly supported the view that magnesia and ferrous oxide were mutually replaceable without limit in this mineral. In this respect, cordierite fell into line with the magnesia-spinel-hercynite and rhombic pyroxene group of minerals. Material support was thus given to the view which he (the Author) had taken that ferrous oxide and magnesia, in the critical rocks considered, were to be grouped together as a single component.

5. *The* STRUCTURE *of the* BOWMORE-PORTASKAIG DISTRICT *of* ISLAY.

By JOHN FREDERICK NORMAN GREEN, B.A., F.G.S.

(Read April 18th, 1923.)

[PLATES V & VI.]

CONTENTS.

I. INTRODUCTION.

THE island of Islay occupies a peculiarly critical position in connexion with existing controversies regarding the Highland metamorphic rocks.

The history of the various opinions held on the North-West Highlands is given somewhat fully in the Geological Survey Memoir (2, pp. 11–32).[1] In brief, it was generally believed for many years that the geology of the Highlands was comparatively simple. The apparent succession in the north-west was accepted as the true one, and, as Cambrian rocks there underlay the gneisses and schists which covered the greater part of the Highlands, these were supposed to be Palæozoic rocks, regionally altered by post-Silurian movement. Although Nicol had argued that the succession was deceptive, and in 1860 had in reality indicated the correct solution of the main structural problems, Murchison and his supporters long maintained their position. The chief point at issue was settled by the work of Lapworth, published in 1883, after which the 'upward succession' was abandoned.

But the unidentified gneisses and schists at the top of the apparent succession: that is, those above the Moine Thrust, covering most of the Highlands, were still regarded as largely altered Palæozoic rocks, although the original evidence for this view had disappeared. Lapworth held the 'eastern schists' to be, unlike the Lewisian Gneiss, of post-Silurian dynamical manufacture from Archæan and later rocks.

[1] Numerals in parentheses refer throughout to the bibliography, § X, p. 100.

The Geological Survey, mapping down the west coast of Scotland along the great thrusts, accepted, generally speaking, the theories of Lapworth, the tendency being to treat the schists that spread over the mountain-area beyond the Moine Thrust as Torridonian and later sediments, dynamically metamorphosed in post-Silurian times. Exposures of Lewisian type were looked upon as inliers.

The officers of the Survey were, however, also engaged in mapping the 'Dalradians' of the South-East Highlands, where one of its members, Mr. G. Barrow, built up an altogether different series of hypotheses. Having established that the south-eastern boundary was also a thrust, he regarded the whole of the Dalradian rocks as Archæan, and equivalent in age to the pre-Torridonian Lewisian Gneiss and Loch Maree Schists, any petrographical differences being referred to varying grades of metamorphism (substantially Nicol's view). He considered the metamorphism to be entirely pre-Torridonian and fundamentally thermal in origin. He insisted on the identification of a single sequence of rocks stretching across Scotland from east to west.

Obviously, these two lines of work must ultimately cross and overlap at some critical point, where a part at least of the differing views could be tested over the same ground. An ideal locality is found in Islay, where the South-East Highland sequence and the Lewisian Gneisses were found to come together, and where the geologists working southwards along the Moine Thrust and those working south-westwards from the Aberdeen district must meet. The greater part of Islay is, further, especially fitted for the investigation of Highland problems, in that the rocks are well exposed and in a state of very slight metamorphism, closely resembling ordinary unaltered Palæozoic strata.

The official Geological Survey maps of Islay were published in 1898 and 1900 respectively, and the memoir (3) in 1907. The chief conclusions (apart from certain points affecting the south-eastern part of the island) were as follows:—

(i) The Rhinns, or western peninsula of Islay, was composed of Lewisian Gneiss overlain by Torridonian.

(ii) The Torridonian continued across the gap between the Rhinns and the eastern portion as the 'Bowmore Grits'.

(iii) These Bowmore Grits were covered by a series (which, for brevity, I have termed henceforth the 'Islay Series') of quartzites, phyllites, limestone, etc., brought up by a great thrust, the 'Loch Skerrols Thrust'.

(iv) As to the order of this series, a conglomerate (Portaskaig Conglomerate) was regarded as younger than the Islay Limestone.

(v) Folded into the Islay Series were certain later dolomitic and quartzitic rocks, the 'Dolomitic Group', believed to be the equivalent of the Cambrian of the North-West Highlands.

In 1916 Mr. E. B. Bailey read before the Geological Society a paper entitled 'The Islay Anticline', which was published in the

following year (4). The more important conclusions affecting Northern Islay were

(i) The historic view with regard to the Lewisian-Torridonian nature of the Rhinns was confirmed.
(ii) The Bowmore Sandstone was separated from the Torridonian of the Rhinns by a great fault, as had been suggested by Mr. Barrow.
(iii) The 'Loch Skerrols Thrust' was confirmed, and correlation with the Moine Thrust suggested.
(iv) The Dolomitic Group was held to be intercalated in, not folded into, the Islay Series.
(v) The view of the officers of the Geological Survey that the Portaskaig Conglomerate was younger than the Limestone was confirmed. The structure of Islay was regarded as anticlinal.

During the discussion of this paper a communication was read from Dr. B. N. Peach, in which, *inter alia*, he controverted Mr. Bailey's view that the Dolomitic Group was an intercalation, and repeated that the 'Bowmore Sandstone' extended into the Rhinns, crossing the great fault inserted by Mr. Bailey.

Mr. G. Barrow, however, who had spent a fortnight in Islay, made some sweeping assertions as to the structure. While supporting Mr. Bailey's conclusions with respect to the fault east of the Rhinns and to the intercalation of the Dolomitic Group, he said that the Bowmore Sandstone was also part of the Islay Series; that the Loch Skerrols Thrust had no existence; that the Limestone was younger than the Portaskaig Conglomerate; and that the structure was, therefore, synclinal.

At the time when Mr. Bailey's paper was read, I had already concluded that Islay must be looked upon as perhaps the most critical area involved in the Highland controversies; and I naturally inferred from the paper and discussion that a hypothesis, such as that put forward by Mr. Barrow, which, when it arrived at the critical area, demanded the abolition of an immense thrust, proved by very detailed mapping, was not worth much further consideration. But, on looking afterwards at the account of the Bowmore Sandstone in the Geological Survey Memoir (3, pp. 25–27), I was impressed by two curious facts, which had not been mentioned in Mr. Bailey's paper, or in the discussion thereon. These were, first, the presence of massive epidiorites in the Bowmore Sandstone, whereas such rocks were entirely unknown elsewhere in the Torridonian, or in demonstrably later Scottish strata; and, secondly, the occurrence of granite-pebbles. It was stated in the Memoir (p. 26) that

'pebbles of quartzite, quartz-schist, granite, felsite, and stained quartz were obtained, representing an assemblage of rocks identical in character with that illustrated by the pebbles of the Torridonian arkoses of Applecross, Loch Torridon, and elsewhere in the North-West Highlands'.

But, in the North-West Highland Memoir (2, pp. 279–284, etc.), granite is not recorded in the list of pebbles noted in the Applecross Group of the Torridonian System. Indeed, it would appear that granite-pebbles are absolutely unknown in any part of the Torridonian other than the basal beds. Still more remarkable, the

map (Scotland, 19) showed an epidiorite cutting, and therefore presumably later than, the thrust. m Bowm

It was clear that there was something mysterious about this Bowmore Sandstone, and I decided to examine it at the first opportunity, which did not arise until 1921.

II. Petrography.

In order that the various lithological correlations made in the following pages may be properly supported, a more detailed description is required than has hitherto been given of the different members of the Islay Series concerned in the structure of Northern Islay (the formations which succeed the Islay Quartzite in South-Eastern Islay have not been studied, and are omitted). In the first place, it is essential to define certain of the terms used; and this is the more important, as it became obvious, at an early stage of the work, that a large amount of confusion and controversy has been occasioned in Islay by an unusual extension of the term 'quartzite', which has been constantly used to cover arkoses with 20 to 30 per cent. of felspar and slates of greywacke aspect. Referring to the northern part of the island, the Survey Memoir (p. 43) observes:

> 'The quartzite included in this series ranges in texture and composition from a coarse felspathic pebbly grit through a massive fine-grained purely siliceous quartzite to a flaggy impure rock which might be described as a sandy phyllite,'

and the word has often been applied to rocks which, on examination in the field, prove to be unlike quartzite properly so called.

The classic writers seem always to use 'quartzite' for an almost pure siliceous rock. Lyell ('Principles' 9th ed.) defines it as 'an aggregate of grains of quartz, sometimes passing into compact quartz'. Sir Archibald Geikie ('Textbook' 3rd ed.) writes:

> 'It is a granular to compact mass of quartz, generally white, sometimes yellow or red, with a characteristic lustrous fracture .... the rock originally consisted of a tolerably pure quartz-sand'.

Prof. C. K. Leith ('Metamorphic Geology' 1915, p. 122) states that when a quartz-sand

> 'becomes so thoroughly cemented that it breaks through the clastic grains, it is called a *quartzite*. The cement then is nearly all, if not entirely, quartz';

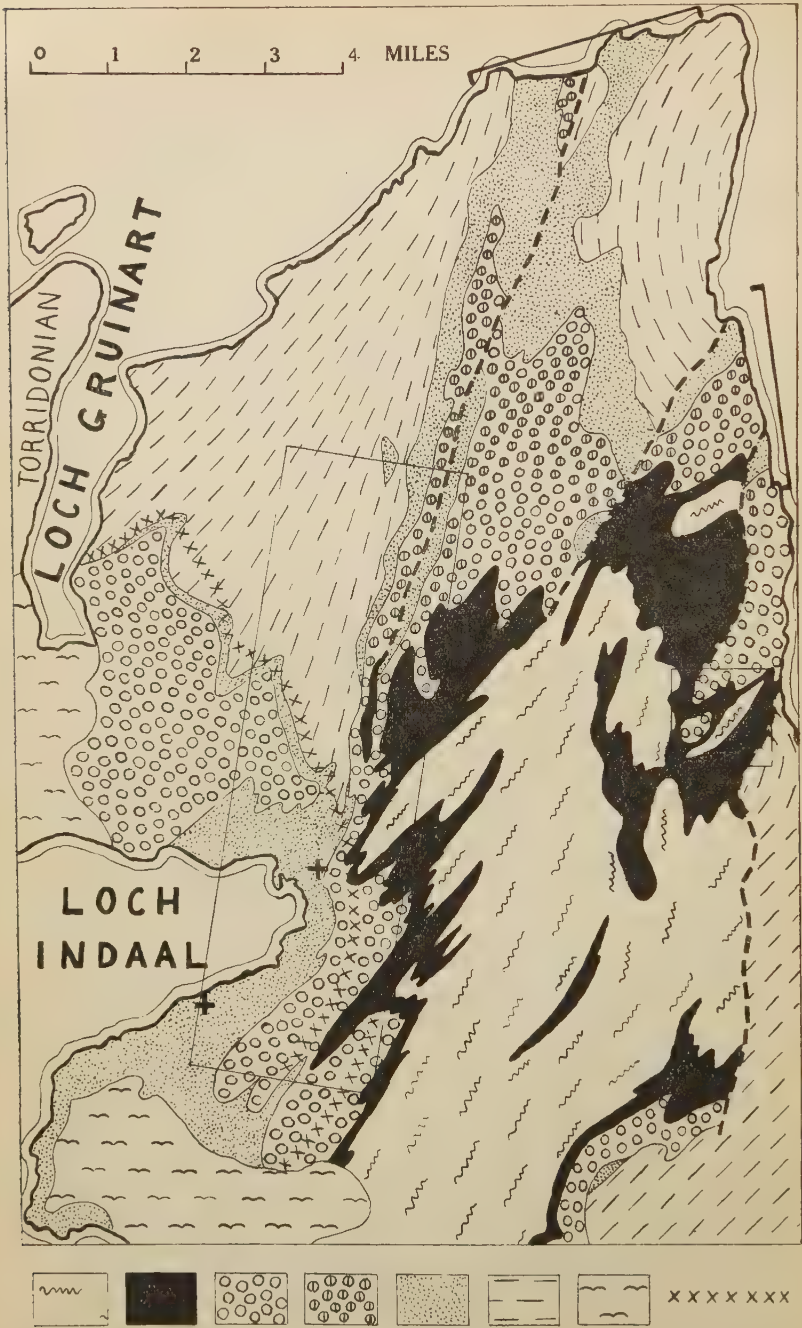
and later he writes:

> 'by cementation quartz-feldspar-sand becomes arkose and quartz-feldspar-ferromagnesian sand becomes graywacke' (*op. cit.* p. 130).

The foregoing quotations, which could be easily multiplied, show that, in general usage, quartzite signifies a fairly pure quartz-rock. An important point is that such a rock changes but little in external aspect with higher metamorphism, so that no change of name is necessary; whereas felspathic or argillaceous rocks change greatly.

For the purpose of this paper the term arkose has been applied to quartzose rocks with scanty matrix, in which 10 per cent. or

Fig. 1.—*Index sketch-map of part of Islay, oriented north and south.*



1 = Dark slates. 2 = Limestone. 3 = Portaskaig Beds. 4 = 'Lower Quartzite'.
5 = Dolomitic Group. 6 = Quartzite. 7 = Alluvium, Raised Beach, etc.
8 = Position of the supposed 'Loch Skerrols Thrust'.

more of the grains near the average size of grain (grade) are felspar. In stating this proportion, the average has been taken of a number of counts in microscopic fields, usually only to the nearest multiple of 5 per cent. In most of such rocks in Islay the proportion is about 20 per cent.

Rocks in which an argillaceous matrix is more plentiful are in Islay fine-grained and often cleaved. The felspar is difficult to distinguish. Such sandy rocks in which obvious felspar + argillaceous matter can be roughly estimated at more than 10 per cent. of the whole are called sandy slates, greywacke-slates, or greywacke; but I have not met enough gradations in Islay to be able to generalize.

In the following description I have tried to distinguish between what is, and what is not, generally agreed regarding the order of succession.

At one end of the sequence come

1. The Dark Slates (Mull of Oa Phyllites).—A rather soft, dark-grey, silty slate, usually pyritous. It contains a great deal of clastic chlorite. Where I have seen it, it is not phyllitic, but resembles a Palæozoic slate.

1·2 The Calcareous Passage-Beds.—The passage between the Dark Slates and the Limestone is composed of interbedded white limestone and calcareous black mudstone or slate, often micaceous. These beds are often exposed, and are useful in mapping.

2 The Limestone.—A blue limestone, much resembling many Palæozoic limestones. It is minutely crystalline, and usually sheared and contorted. It is sometimes rather sandy, the grains being much corroded; and often contains numerous quartz-veins, possibly representing dissolved sand.

In the north of Islay the junction between the Limestone and the Portaskaig Beds is usually direct. There may be an intervening band of dolomite; but, in view of the occurrence of dolomite within the Portaskaig Beds, it may be regarded as part of the latter. In a few places (for instance, by Drom Alaidh, near Scarrabus) a little sandy black slate comes in between. It is different from the Dark Slates, being ferruginous and containing scattered sand- and grit-grains. Where I have seen this, the black slate is not important enough to be mapped separately; but there is some reason to think that it is thicker and more continuous farther south.

3 The Portaskaig Beds.—This horizon has formerly been called the 'Portaskaig Conglomerate'. But a great part of the material placed by the Geological Survey under this head is not conglomeratic, and, in order to avoid misconception, I propose to use a less closely defined term which can, if good reason be shown, be somewhat extended. The following description refers only to rocks coloured by the Geological Survey as conglomerate:—

The dominant material is rounded quartz-felspar sand and grit; the amount of felspar increases with the grade: for grade 0·5 mm. it is usually 25 per cent. The felspars are mainly orthoclase and acid oligoclase; about one in six is microcline. The quartz is rarely 'hairy'; the maximum proportion of such grains that I have found is 1·5 per cent. The interstitial material, mostly very scanty, is sericitic, often silty. The rock is massively bedded, rough, pale green or grey on fracture, and of somewhat darker colour on the weathered surface.

Another common type is of much the same composition, *plus* a variable amount of dolomite; as dolomite increases, the rock becomes finer in grade. These are green in colour, but weather with a thick porous rusty-brown crust. They are commonest in the east, and decrease northwards and westwards.

A third type is a greywacke-slate with clastic muscovite, which is rare in the other varieties. Rarely this type is uncleaved, when it corresponds to the argillite of Canadian geologists.

Occasionally films occur which are rich in ilmenite-grains.

The greater part of the series is not pebbly, but bands with pebbles or boulders are common. The smaller (up to, say, 1 cm. in longest diameter) are quartz, felspar, and quartzite, sometimes dolomite. The big boulders are predominantly quartzite, though dolomite is very abundant in some places, especially where the matrix is dolomitic. More important, however, are the boulders of red nordmarkite (sometimes pulaskite) which, as Dr. J. S. Flett has pointed out, are identical with those that he has described from the Loch-na-Cille Conglomerate. They often present a characteristic appearance in hand-specimen, because of the manner in which the felspars are cut up by meandering strings of quartz. Some of the Islay specimens contain a good deal of quartz, and might be termed alkali-granite. Zircons may be found, although they do not seem to be so large and plentiful as at Loch na Cille.

The metamorphism of the arkoses is very low. Felspar, muscovite, and chlorite seem quite unaffected. Quartz-grains are pitted, showing a minutely scalloped outline under the microscope; and, where in contact, suture together. The sutures may deepen, and give a granulated appearance. The sericite may be accompanied by a mineral of low birefringence, possibly albite. Dolomite usually segregates into rhombs packed in among the clastic grains, of diameter ·05 to ·2 mm. The rhombs seem to have made room for themselves by solution of neighbouring grains, and it is noticeable that suturing and granulation are better marked in rocks with, than in rocks without, dolomite.

The manner in which the conglomeratic portions were formed is so far uncertain. The matrix resembles an ordinary marine basal grit, but the arrangement of the larger constituents is peculiar. They are hardly ever in contact. Lines of pebbles may sometimes be seen evenly spaced out, but the ordinary distribution is most irregular; curiously enough, some of the biggest boulders are set

in the finest matrix: the biggest granite-boulder that I have seen, 70×50 cm., was isolated in a silty slate. Thomson records a granite-block 4 feet 10 inches long, from a quarry in which granite-boulders predominated. So far, no better suggestion has been made than that author's, that floating ice was concerned. In composition and structure the rocks have notable resemblances to the Huronian Cobalt Conglomerate of Eastern Canada, which is ascribed to ice [1]; and the presence of pre-Cambrian ice-action in Scandinavia is now well established. It will be shown later that parts, at least, of the conglomerate were at times exposed to the air.

The Dolomitic Group.—Mr. E. B. Bailey has placed these rocks between the Portaskaig Beds and the Islay Quartzite, and reasons will be given in support of his view. The succession within the group is, however, a matter of considerable difficulty, which will be discussed in a later part of this paper. At present only the various lithological types will be described.

The greater part of the group consists of 'Dolomitic Flags',[2] banded alternations of dolomitic silt or sand. The dolomite is largely in the form of minute rhombs; the sand-grains are greatly corroded and, when in contact, closely sutured one into the other. Some secondary silica is usually present. These flags can in several places be seen to pass into a different type of rock, in which pure dolomite is set in an intricate network of crystalline quartz, and is studded with knots and strings of the same mineral. This variety seems to be produced from a silty bed as the result of the segregation of quartz and dolomite. Its exposures are shown on the Geological Survey map as dolomite, but I believe it to be merely an altered form of a dolomitic silt. A similar rock is found in the Cobalt Series of Eastern Canada, but is regarded as probably a replacement product.[3]

Whereas the ordinary dolomitic flag disintegrates readily, this segregated form, owing to the indestructibility of the quartz network, is highly resistant. In consequence, it is commonly exposed inland, and an erroneous view of its importance might be accepted, were it not for the coast-sections which show it to be quite subordinate.

At, or near, one edge of the dolomitic flags there is sometimes found a band of rather pure cream-coloured dolomite.

Within the Dolomitic Flags occurs an impersistent band of peculiar quartzite, which I term the *Bluish Quartzite*. It is a blue and white false-bedded quartzite of irregular texture, much of it decidedly felspathic. The bedding is marked by a blue stripe, and rarely a thick blue bed may be seen. The apparent thickness is about 100 feet at a maximum; but the band thins out northwards, and I have not found it on the north coast.

[1] M. E. Wilson, Mem. Geol. Surv. Canada, No. 103 (1918) pp. 60, 137–140

[2] See Geological Survey specimens 8679 to 8686.

[3] *Op. supra cit.* pp. 124–27.

A slide of one of the felspathic white portions contains nearly 10 per cent. of felspar. On the other hand, a coarse blue specimen is highly siliceous, with rounded pebbles measuring up to 2 mm. in diameter. These pebbles and grains are outlined in opaque (? ferruginous) material, and are cemented by quartz in optical continuity.

There are also in the Dolomitic Group certain siliceo-argillaceous flags ('sandy shales and flags' of the Geological Survey) which will be described in detail later, wherefore it is unnecessary to give a petrographical account here.

The nomenclature of the quartzites that come next to the Dolomitic Group is in some confusion. The officers of the Geological Survey included the southern part of them with the southern exposures of the Portaskaig Beds as 'Beinn Bhan Quartzite'. Mr. Bailey put them with several other horizons together as the 'Islay Quartzite Group'. Some name is needed for the great zone of true quartzite which comes north-west and south-east of the rocks hitherto mentioned, and I propose to use the designation *Islay Quartzite*. This thick mass is divisible into three sections, which I term the *White Quartzite*, the *Main Quartzite*, and the *Pebbly Quartzite* respectively.

6 *The White Quartzite*.—That part of the Islay Quartzite which is nearest the Dolomitic Group is a very pure siliceous rock, with a white splintery or conchoidal fracture, and a smooth, intensely white, weathered surface. Felspar is almost absent. The rock is markedly false-bedded, bedding-planes being indicated by dark ferruginous films which weather out to a rusty colour. Jointing is rather close.

As this horizon is well exposed, owing to its hardness, and is immediately recognizable, it is most valuable in mapping.

6 *The Main Quartzite*.—This is a suitable term for the thick, somewhat felspathic, rock which is the chief mountain-builder of Islay. It is massive, coarse-grained (the grains being commonly 0·5 to 1·0 mm. in diameter), with a splintery white fracture, and a rather rough pale-grey weathered surface. In the slides examined the rock is a good deal granulated, so that counts cannot be made; but the proportion of felspar to the whole rock varies from 3 to 7 per cent.

The Pebbly Quartzite.—My work has not touched this, the other edge of the Islay Quartzite.

III. The so-called 'Lower Quartzite'.

Before proceeding to examine the Bowmore Sandstone, it is desirable to clear up the question of the rocks which Mr. Bailey has classed as the 'Lower Quartzite'.

The succession north-westwards from the central axis of Islay

(whether synclinal or anticlinal), though much complicated by minor folding, is broadly (1) Dark Slates; (2) Limestone; and (3) Portaskaig Beds. North of this is a series of outcrops of the Dolomitic Group, forming a rude horseshoe on the map, convex northwards. On the convex side are large outcrops of the Islay Quartzite, recognized as such by both Dr. Peach and Mr. Bailey. The White Quartzite is always in contact with the Dolomitic Group, except where there is evidence of faulting at the junction, as at Bagh an da Dhoruis on the northern coast (fig. 2, p. 82).

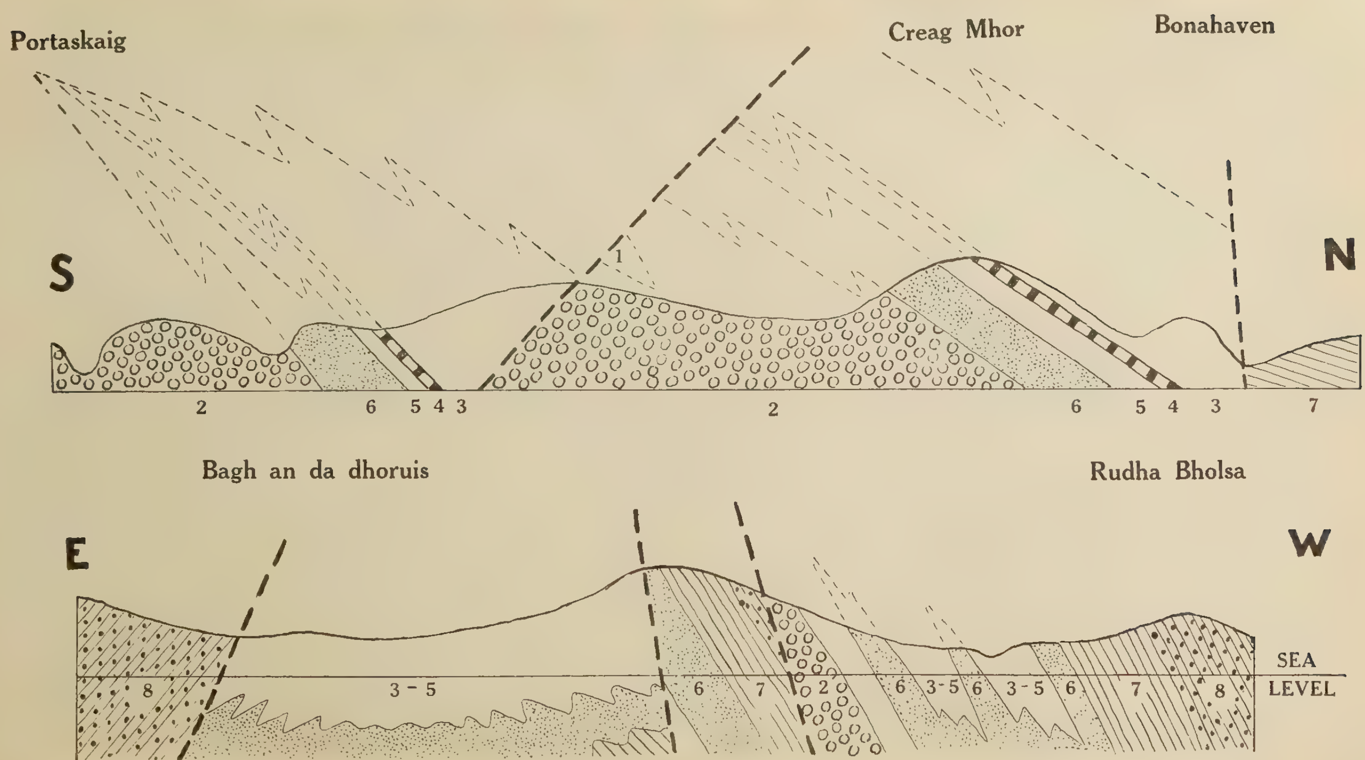
On the concave side are rocks, claimed by Dr. Peach as being also part of the Islay Quartzite brought up by folding (3, pp. 12, 43, 49, 50, etc.), but considered by Mr. Bailey to be a quartzite at a different horizon (4, pp. 147–151). Actually, the composition of these rocks, unlike that of the Islay Quartzite, shows that they are not quartzites at all, in the ordinary acceptance of the word. They are mostly arkoses and greywacke-slates, both occasionally conglomeratic. Some of the less felspathic arkoses superficially resemble the Main Quartzite, although distinguishable by darker coloration and higher proportion of felspar; but I can say with some confidence that nothing like the White Quartzite is found in the disputed area.

Half a mile of coast north of Ardnahoe, near Bonahaven, is mapped as 'Lower Quartzite'. The rocks observed are massively bedded green or grey arkoses. One north of Con Tom was selected as somewhat quartzitic in appearance, and proved to be about 0·3 mm. in grade, with scattered larger grains and 18 per cent. of felspar. There was hardly any matrix, so that the grains were well sutured. Half-way along this stretch of coast is a coarse arkose, weathering dark brown and somewhat porous; it is presumably dolomitic. The same series is again mapped on the coast at Caol Ila. A specimen from a quarry a quarter of a mile inland has a grade of 0·5 mm.; the percentage of felspar is 20, but as there are a number of quartz-grains above the average size, the bulk proportion is a good deal lower; sericitic matrix is very scanty.

North-west of Balulive a rock, rather like the Main Quartzite at first sight, occurs at the ford across the Abhuinn an-t-Sratha Luachraich. It is grey-green, with 11 per cent. of felspar. Much of the large central area of 'Lower Quartzite', lying south of Loch Giurbheinn, is badly exposed. East of this, south-west of Loch an Dubhaich, it is conglomeratic in places; and in Gleann a Chapuill Bhain, almost in the middle line of the 'horseshoe', the arkoses include bands weathering brown and porous, associated with other bands carrying pebbles of quartz and dolomite. About Giur Bheinn itself many of the rocks are conglomeratic. I have not visited the area north of Giur Bheinn.

East of Loch Carn nan Gall the rocks are of finer grain than usual, looking like sandstones in the field. A specimen from the top of Carn nan Gall proves to be an irregular argillaceous silt, studded with larger grains, 0·5 to 1·0 mm., of quartz, felspar, and green biotite (one of which encloses a crystal of hornblende). Another, compact, with conchoidal fracture, from the southern end of the loch, is an even-grained argillaceous sandstone, the sericitic matrix being about 20 per cent. of the whole. It contains a fair amount of felspar and a little clastic muscovite. On and south of Tais Bheinn, the beds nearest the Dolomitic Group are greywacke-slate, with quite 50 per cent. of argillaceous matter; they are overlain by arkose-sandstone. In the strip repeated by the fault west of Tais Bheinn the 'Lower Quartzite' is not well exposed. Where seen, it is a medium arkose, except immediately west of

Fig. 2.—*Sections along parts of the eastern and northern coasts of Islay, on the scale of 1 : 26,950.*



1 = Limestone. 2 = Portaskaig Beds. 3 = Dolomitic Flags. 4 = Bluish Quartzite. 5 = Dolomitic Flags. 6 = Bowmore Flags
7 = White Quartzite. 8 = Main Quartzite. [Dykes are omitted.]

Maol nan Caorach, where it is coarsely conglomeratic, with granite- and quartzite-boulders 15 cm. long.

A highly sheared specimen from the junction with the Dolomitic Group near Loch Cam seems originally to have had the composition of a pebbly grit, with only 4 per cent. of felspar. If this comes from the 'Lower Quartzite', it is the only rock from it of quartzitic composition that has been observed.

The rocks referred to 'Lower Quartzite', near Port a'Chotain on the northern coast, are dealt with on p. 92.

Dr. Peach's identification is plainly untenable, as the beds on the convex side of the 'horseshoe' are quite unlike those on the concave side, and so the Dolomitic Group, as Mr. Bailey holds, must lie between the Islay Quartzite and the so-called 'Lower Quartzite'.

But the above description also shows that no distinction can be maintained between the 'Lower Quartzite' and the Portaskaig Beds. The identity with the matrix of the conglomerate is obvious; the bed, or lenticle, is overlain and underlain by conglomerate; it is itself conglomeratic in places; and, at its southern extremity, the upper and lower conglomerates appear to come together naturally (no evidence could be found of the mechanical thinning-out suggested by Mr. Bailey). The rocks might be treated as a sandstone lenticle in the Portaskaig Beds, but there are serious objections to grouping them with the Islay Quartzite, instead of with the beds to which they are lithologically equivalent and in which they seem to be enclosed. As I am unable to draw any line between the 'Lower Quartzite' and the Portaskaig Beds, I have included the former with the latter in mapping.

This rearrangement leads to a notable simplification of the map. On both sides of the main fold of Islay, the Portaskaig Beds, as just defined, are succeeded outwards by the Dolomitic Group, or the Islay Quartzite only; and the chief structural problem, apart from the Bowmore Sandstone, is reduced to finding a solution of the relations between these three groups.

IV. The Bowmore Grits and Flags.

Apart from a fragment in the Rhinns, the series of rocks included under the title 'Bowmore Sandstone,' on the Geological Survey and Mr. Bailey's maps, covers an area of some 18 square miles (including parts within their boundaries concealed by alluvium, raised beach, etc.) lying about the head of Loch Indaal; and, according to these maps, ending off against the Loch Skerrols Thrust. The series consists of two distinct types: the first, massive sandstones, which have been denominated 'Blackrock Grits'[1]; the other is of finer grain, and of a flaggy habit.

The grits are greenish or greyish on a fractured face, and generally also on the weathered surface. Occasionally, especially where much jointed, they are stained red, although green cores can be found. They weather massively, and do not display bedding particularly well.

[1] See Geological Survey specimens 6231 to 6236, 7586, 7587.

The only coast-section is that at Blackrock on the northern coast of Loch Indaal, and is about a quarter of a mile long. These grits can also be conveniently studied in natural and quarry exposures in the district north of the Bowmore-Portellen road, at from half a mile to a mile and a half from Bowmore.

Most of these rocks are of grit or coarse sand grade, and consist of quartz and acid felspar, with a scanty binding of sericite. Only about 1 per cent. of the quartz is 'hairy'. From one in four to one in six of the felspar-grains are undoubted microcline. Specimens from Cnoc Donn and Tobar an-t Suidhe (Blackrock) have grade 0·6 and 0·5 mm. respectively, with over 25 per cent. of felspar. Slides of coarser material from the latter locality show felspar up to 40 per cent.; but this relation between felspar and grade is not invariable, as a rock from the Bunanuillt Burn, east of the head of Loch Gruinart, of grain 1·0 mm., has less than 15 per cent. In all these the quartz-grains, when in contact, are sutured one into the other, and some show a little granulation. Another specimen from near Blackrock of lower grade, 0·2 mm. (though with quartz-pebbles), has a plentiful sericitic ground-mass, so that there is little suturing.

Some few exposures may be found weathering, not green-grey, but brownish and slightly porous. In a specimen from Maol na Coille the slide resembles the ordinary arkose-grit of the district: it has, however, in addition little rhombs, 0·1 to 0·2 mm. long, like those of dolomite in the Portaskaig Beds, packed in among the grains of quartz and felspar.

Intercalations of greywacke-slate are rare, but have been noted, measuring up to a foot in thickness, at Blackrock and on Beinn Churlaich, 2 miles south-east of Bowmore. A specimen with numerous ilmenite-grains comes from Tobar an-t Suidhe.

From the foregoing description it is plain that the 'Blackrock Grits' differ in no respect from common types of the Portaskaig Beds; they are identical in texture, grade, proportion of felspar, character and shape of both quartz- and felspar-grains, nature and amount of the scanty matrix, suturing, fracture, colour, and weathering. Like them they are often pebbly, and, though not containing such coarse conglomerates, the pebbles in these 'Blackrock Grits' run up to 3 and 4 cm. in length, and have the same discrete arrangement as the pebbles and boulders of the Portaskaig Beds.

Up to 1 cm. a considerable number of the pebbles are felspar; the larger are mostly quartzite, usually lilac or blue, occasionally crimson.[1] There are also various schistose rocks and rounded fragments of red granite, exactly like the red alkali-granite and nordmarkite of the Portaskaig Beds. These granite-pebbles have been obtained at Blackrock (as noted by the Geological Survey), at An Carn, north of Loch Sibhinn; and at a quarry by the side of

[1] Similar coloration apparently due to some stain, is known elsewhere in the Highlands; see 'Ben Wyvis, &c.' Mem. Geol. Surv. Scot. 1912, pp. 29, 36.

the Portellen road near Cnoc Donn (see the south-eastern corner of the map, Pl. VI), where many specimens have been collected from heaps of fresh road-metal. Slides of these pebbles do not reveal any difference from the alkali-granites and nordmarkites of the Portaskaig Beds; they consist of quartz, perthitic orthoclase, microcline, albite, usually with intricate cross-twinning, sometimes also magnetite and patches of chlorite, corresponding to Dr. J. S. Flett's account of the boulders of the Loch-na-Cille Conglomerate.[1]

Pebbles of nordmarkite-porphyry are also found. One from the quarry near Cnoc Donn has a fine-grained quartz-felspar groundmass, with phenocrysts of perthite and albite.

The identification of the nordmarkite-suite completes the petrographical evidence that the grits of the Bowmore Sandstone are simply the Portaskaig Beds. The structural evidence will be stated later. I found the rocks quite indistinguishable in the field, and am at a loss to understand on what grounds they have been separated.

A small area about Gortan in the Rhinns has been correlated by the Geological Survey with this formation. The point is not of great importance in connexion with the present enquiry; but it may be noted that the exposures consist of dark-green sandy slates and red arkose-grits unlike anything seen in the main area, and differing petrographically in many respects. So far as I have examined them, they are continental in type, as opposed to the marine-like strata east of the Rhinns.

The remaining 8 square miles of the area mapped by the Geological Survey as Bowmore Sandstone is composed of the flaggy rocks already mentioned. Some 5 miles of excellent coast-section reveal them as consisting entirely of siliceo-argillaceous flags, rarely somewhat dolomitic, which, though varying much in aspect, are essentially composed in all cases of a mixture in varying proportions of two constituents: one, an angular felspathic sand, varying from silt up to 0·3 mm. grade in the coarsest sandstones, and always containing a small amount (usually between 1 and 2 per cent.) of epidote-grains of the same grade, and of clastic muscovite; the other, argillaceous material of a very dark greenish-grey colour, sericitic in thin section.

Most of the varieties of these flags, which may be termed the Bowmore Flags, fall into two classes. The commonest was originally a silty clay, now a rather hard rock, which might be called greywacke, of varying tints of grey or green-grey, and presenting a somewhat speckled appearance. In a hand-specimen, the bedding, if visible at all on a broken surface, is marked by slightly darker striping. This type weathers into good flags on the coast; but the flaggy structure is rarely so obvious inland, as the weathering follows joints and cleavage rather than bedding. The

[1] 'Geology of Knapdale, &c.' Mem. Geol. Surv. 1911, p. 76.

surface is then rough and brown. The second class consists of alternating beds of siltstone or sandstone, of a pale yellow or pink tint, from a few millimetres to a metre thick, and greenish-black argillaceous material, usually thin, often a good deal squeezed. The latter may occasionally be found torn into lenticles. This type shows highly marked flagginess, both inland and on the shore.

Some of the flags contain a little carbonate, probably all dolomite, as it occurs both in elastic grains and in rhombs. I have found some bands rich in green biotite, not flaky, but in irregular grains. In a sandstone from Laggan Bridge House a large part of the matrix is such clastic biotite.

In places the flags are deeply stained red or brownish-purple. This is especially noticeable where, as sometimes happens, the rock is so closely jointed that even the shore-weathering is no longer flaggy. Cores of the usual green-grey colour can be found in the larger joint-blocks. In the Geological Survey Memoir some of these flags or 'grits' are described as 'brown'; but the brown or red coloration is really adventitious staining or weathering, the tint being usually confined to a surface-skin.

The coast-section southwards from Bridgend to the north of the Laggan River, especially the 2 miles from Gartbreck to Laggan Head, discloses an astonishing series of these flags, dipping for the greater part steadily south-eastwards at an inclination of about 40°, and presenting the simulacrum of a conformable sequence of enormous thickness. If it were a truly continuous dip, the thickness would be fully 7000 feet; but investigation shows occasional contortions or minor folds, and, east of Laggan Head, small-scale isoclinal folding is obvious. Also the 'Blackrock Grits' come in along the strike in a way that makes it plain that the series as a whole has a low, almost horizontal, sheet-dip. From evidence obtained in other parts of the island, I do not think that the real thickness much exceeds 200 feet.

There is no difficulty in identifying the Bowmore Flags in the Islay Series, east of the supposed 'Loch Skerrols Thrust', as the siliceo-argillaceous flags of the Dolomitic Group, well exposed in the coast-section north of Caol Ila distillery, near Portaskaig. They occur again a third of a mile south of Bonahaven. There are further exposures on the northern coast at Port a'Chotain and west of Port an-t Sruthain, as well as at two intermediate points between the two last-named localities. Good sections are seen at many points inland, notably on the western flanks of Tais Bheinn in the north-eastern corner of the map (Pl. VI). They can be studied especially well south of Bonahaven, where they are readily accessible, and can be seen in beach, cliff, and inland sections. It is unnecessary to give any separate petrographical description, as every item in that given of the flags in the Bowmore area applies, except the occasional secondary red staining, which is not of importance. There is the same range of varieties (a band rich in clastic green biotite has been noted on the eastern coast, north of Caol Ila), and whether on the coast or inland, in hand-specimen or under the

microscope, no difference can be detected. It will be shown subsequently that the stratigraphical relations are the same, and so there is no reason for using any different nomenclature. They will all be termed 'Bowmore Flags'.

These flags, which are easily recognizable, are of primary importance in the tectonics of Islay, and their position will now be discussed.

V. The Supposed 'Loch Skerrols Thrust'.

In discussing the stratigraphical position of the rocks which have been called 'Bowmore Sandstone' and its bearing on the structure of this part of Islay, it is convenient to begin with the wedge of Limestone and Portaskaig Beds, on which the farm of Tallant is situated, a mile and three-quarters from Bowmore. It is shown on the 1-inch map (Scotland, 19) projecting into the Bowmore Sandstone area, bounded on the north-west by the Loch Skerrols Thrust and on the south-east by a normal fault. The rocks on the boundary of the wedge are best exposed about a quarter of a mile south-west of Tallant Farm, immediately north of the Bowmore road (see map, Pl. VI); and a traverse from east-south-east to west-north-west crossing these exposures will now be described. In view of the importance of the area, a good deal of detail will be noted.

On approaching Cnoc Donn from the Portellen road, the first solid rocks seen are greenish, sometimes pebbly, arkoses of the Portaskaig Beds (Blackrock Grits), the proved outcrop being a quarter of a mile broad. Then a little conglomerate, slightly dolomitic, appears, followed at once by the Islay Limestone, with an outcrop 180 yards across. (The Calcareous Passage-Beds have been quarried by the Portellen road, in the broader northern part of the outcrop, where there is probably a small concealed outcrop of the Dark Slates.) The limestone is followed at the road to Tallant by 100 yards of slightly dolomitic conglomerate and grey arkose. There is then an outcrop, about 150 yards broad, of Bowmore Flags. The exposures nearest the conglomerate are siliceous, with flaggy weathering. Immediately east of a path to a house standing 300 yards west of Tallant, a knob of the common green-grey argillaceous variety of the Bowmore Flags, well cleaved, has been quarried away; west of the path are seen interbedded siliceous and argillaceous varieties.[1]

Some 8 yards west of the last exposure of the flags comes an outcrop of the White Quartzite. It is snow-white, purely siliceous, with rusty films, and shows false bedding, so that its identity is not in doubt. The false bedding is well seen on a joint-face, and

[1] The Geological Survey map colours these flags as Portaskaig Conglomerate. Nothing at all like them appears in the conglomerate elsewhere. It is possible that they were not so well exposed when the survey was made.

clearly indicates[1] that the beds at this point, which dip on the average about 35° east-south-eastwards, are 'right way up'; and they, therefore, unless inversion has taken place in the 8 yards of unexposed outcrop from the nearest Bowmore Flags, underlie the latter stratigraphically.

There is then a gap of 100 yards, after which sheared White Quartzite, resembling that of the Loch Skerrols area, is exposed at the end of a low ridge, separated by a depression from another low ridge of green arkose, which, as it weathers brown, probably is slightly dolomitic. The Loch Skerrols Thrust is supposed to run along this little depression, which is, however, like that due elsewhere to the Bowmore Flags when occurring between harder beds. The maximum breadth of the flag outcrop must be less than 20 yards.

The arkose begins a long series of the Portaskaig Beds, which are seen, often pebbly, for 1100 yards, after which the Bowmore Flags come in again in great force, and continue to the sea at Bowmore.

The outcrops, therefore, follow each other thus:—Portaskaig Beds—Limestone—Portaskaig Beds—Bowmore Flags—White Quartzite—(Bowmore Flags)—Portaskaig Beds—Bowmore Flags; and the obvious explanation is a succession of folds. If the indication of false bedding be taken as a guide, the sequence is Islay Limestone—Portaskaig Beds—Bowmore Flags—White Quartzite, in two synclines with an intervening anticline. This interpretation is supported by the character of the outcrops. The whole series is shown by contortions in the limestone (well seen in a cutting on the Portellen road) and in the flags of the beach, and also by the dips, to be strongly overfolded towards the west-north-west; consequently, the inverted limb of the anticline would be west of the White Quartzite, and should be the narrower. The Bowmore Flags inferred in this limb have a breadth of less than 20 yards, compared with a proved breadth of 120 yards in the other limb.

An interesting confirmation of the repetition of the Portaskaig Beds east and west of the limestone is found in the occurrence of an epidiorite sill somewhat north of the traverse just described. On the east it is seen by the Portellen road 200 yards south of the 'Two miles to Bridgend' stone, running eastward in a succession of mounds arranged *en échelon* which appear to represent thickened limbs of small pitching folds. On the west it is exposed about Carnbuie, and can be traced at least a mile and a half north-eastwards. Both exposures die out southwards; repetition in the

[1] For the use of false bedding as an index of position, see A. C. Lawson, 'The Archæan Geology of Rainy Lake restudied' Mem. 40, Geol. Surv. Canada, 1913, p. 63; and C. K. Leith, 'Structural Geology' 1914, pp. 132–33. In my experience, it is not easy to find really clear sections. Of course, like ripple-marking, it only indicates the attitude of the particular laminæ observed; and wider inferences need great caution among highly folded rocks.

intervening ground north of Tallant cannot be verified, owing to entire lack of exposures.

Thus the evidence in the neighbourhood of Tallant does not support the presence of a thrust. We may next examine the supposed line of the thrust near Loch Skerrols.

About a mile north-west of the Loch, a quarter of a mile east of Loch Sibhinn, sheared White Quartzite and coarse pebbly arkose are 60 yards apart, east and west respectively of the line. From this point down to Loch Skerrols, a depression runs between ridges of White Quartzite, often highly sheared, and Portaskaig arkoses; in line with this depression on the southern side of the loch are large exposures of Bowmore Flags, indicating an outcrop 300 yards across between sheared White Quartzite and Portaskaig Beds; and it may be inferred that the depression north of the loch conceals flags. The shearing of the White Quartzite, though considerable, does not seem to be more than might be expected at the junction with a soft rock on the inverted limb of an overfold in intensely folded country, and is comparable with that which may be seen in other parts of Islay (see, for example, p. 97).

Farther south these rocks are not exposed until the neighbourhood of Bridgend, where widespread Bowmore Flags suggest that the White Quartzite must have pitched under, and that the continuation of the relations between it and the Portaskaig Beds must be sought east of the line just explored.

As we come round to the east of Loch Skerrols, Limestone and Portaskaig Beds are seen plentifully east and north-east of the loch. The quartzite is not met with, until a point is reached about a mile north of the easternmost extension of the loch, near a road leading to the farm Scarrabus. Here, in an escarpment of rather fine-grained Portaskaig Beds, the White Quartzite is seen a few inches below them, so that the Bowmore Flags must be cut out. This type of junction seems to persist for some way northwards, but at a point by a track 120 yards east of the south-eastern corner of Loch Cam, about 12 feet of Bowmore Flags are seen, cut by a basalt dyke. Some 140 yards farther north, a clear section shows arkose resting upon 20 feet of the flags. The Portaskaig Beds, conglomeratic in places, and the White Quartzite can then be followed for half a mile northwards, dipping 40° east, up to the Allt nan Oisgean, where dolomitic flags come in apparently between the Bowmore Flags and the Portaskaig Beds.

From this point the Bowmore Flags are not exposed for a mile and a quarter along the strike; but, for the greater part of this distance, a terrace, from 12 to 100 yards broad, runs along the eastern slope of Beinn Cham. The hillside of this terrace is composed of White Quartzite (the mass of the hill being Main Quartzite) and the platform often has an elevated rim, in which Dolomitic Flags are exposed in places.

In the gap between Beinn Cham and Beinn a'Chuirn, where two brooks unite, another member of the Dolomitic Group appears, the Bluish Quartzite coming in between the Dolomitic Flags and

the Portaskaig Beds. A more complete section is seen on the northern side of this gap at a ruined croft. On the western fence of the enclosure the Bowmore Flags are well seen, the actual contact with the White Quartzite being exposed. The change from quartzite to sheared flag takes place in a few inches, and seems gradual and perfectly conformable. Dolomitic Flags are seen immediately on the east and, close to the remains of the house, the Bluish Quartzite and Portaskaig coarse arkoses are exposed near together.

The same sequence, though not so well exposed, runs another mile northwards past Lochan Broach (at the extreme north of the map, Pl. VI). In this neighbourhood some Dolomitic Flags come in between the Bluish Quartzite and the Portaskaig Beds.

East of this 3-mile outcrop of the dolomitic group, the Portaskaig Beds are found for from 150 to 600 yards, succeeded in the south by the Limestone. At a crag east of Toll a'Chapuill Bhain, boulders of granite 15 cm. long occur in rocks which Mr. Bailey maps as part of his 'Portaskaig Conglomerate'. They are then cut off by a fault, parallel to the strike, which brings them indifferently against White Quartzite, Bowmore Flags, or Dolomitic Flags. The line of this fault can be laid down with considerable accuracy where it runs into the valley of the Abhuinn Airidh an t-Sluic, so that its hade could there be definitely ascertained with proper levelling. At present, I cannot say more than that the fault-plane dips 10° north of west, at an angle of between 20° and 40°. Crossing the fault, another belt of the Dolomitic Group comes in, in which better exposures are met with than in the belt just described.

At the southern end of the eastern belt the Bowmore Flags are well seen near the road leading from Balole Farm to Loch Cam, overlain by Portaskaig Beds with dolomite-boulders; they appear at intervals for half a mile northwards. Here the Dolomitic Flags come in, and on Carn nan Gillean occurs the complete sequence:—White Quartzite; depression marking Bowmore Flags; Dolomitic Flags, dipping 75° east-south-eastwards; Bluish Quartzite; Dolomitic Flags; Portaskaig Beds. From the top of the carn the outcrop of the dolomitic series can be viewed for 2 miles; the Bluish Quartzite, which is nearly vertical, forms a marked feature, flanked on either side by Dolomitic Flags. The sequence is splendidly exposed on Tais Bheinn, the Bowmore Flags cropping out on the western flank of the hill, overlain by Dolomitic Flags, almost continuously for 200 yards—the finest inland section that I have seen outside the Bowmore area. The Bluish Quartzite has thinned considerably. The basal Portaskaig Beds here are, for at least a mile along the strike, a green sandy slate (greywacke-slate) like the matrix of the coarsest boulder-beds.

The results of this examination of the country about Loch Skerrols and Loch Cam, which, in order that the nature of the evidence may be appreciated, has been described in unusual detail, are as follows:—

(1) The Bowmore Flags lie conformably against the White Quartzite, constituting a passage to the highly dolomitic beds. I agree with Mr. Bailey that the fault marked along this junction on the Geological Survey map is not proved.

(2) The main structure is an isoclinal fold, overturned in a direction rather north of west.

(3) Strong shearing of the White Quartzite along the western limb of this fold suggests that it is the inverted limb of an anticline.

(4) This interpretation is supported by the manner in which the successive members of the Dolomitic Group appear from beneath the Portaskaig Beds, the inference being that they have been cut out southwards by erosion below that conglomeratic horizon.

Along the line of the supposed thrust north of Loch Sibhinn the arkoses and quartzites are never, so far as I have investigated them, exposed nearer one another than 60 yards, so that there is always room for the Bowmore Flags. Mostly, the exposures are poor and distant.

Rocks similar to those of Carnaine (that is, Bowmore Flags) are stated to be seen in the Bunanuillt Burn, but I have not visited the spot. On the shore of Loch Gruinart, 300 yards south-west of Bunanuillt Farm, where the thrust-plane is said by the Geological Survey to be exposed over 'Torridonian grits', I found highly sheared White Quartzite overlying a few square yards of micaceous material, intensely sheared, crumpled, and veined, the axial planes of the puckers being mostly near the horizontal. Much of this rock is friable, but there are augen of hard, blue-grey, fine-grained rock. One of these proves to consist chiefly of quartzose silt, mixed with a third to half of its quantity of dolomite, and cut up by lenticles of ribboned sericite, evidently the remains of argillaceous partings. There is a good deal of pyrites. Rocks similar in colour and composition occur in places near the junction of the Bowmore Flags and the Dolomitic Flags; as, for instance, at Caol Ila, north of Portaskaig. This exposure may be on the inverted limb of an overturned anticline, in which part of the Bowmore Flags, the softest part of the series, may have been locally squeezed out; it cannot be far from the line of the Loch Gruinart Fault, to which the crushing is probably due.

VI. The Sequence in the Dolomitic Group.

The sequence so far appears to be

Dark Slates.
Calcareous Passage-Beds.
The Limestone.
Portaskaig Beds.

Line of Erosion.

Dolomitic Flags.
Bluish Quartzite.
Dolomitic Flags.
Bowmore Flags.
White Quartzite.
Main Quartzite.

The Dolomitic Group is of such importance in determining the structure of Islay that it is desirable to examine other districts in the island, so as to test this sequence.

Northern coast-section.—The country between Tais Bheinn and the northern coast has not been visited. Apparently, the Bluish Quartzite thins out altogether. The northern coast between Rudh'a'Mhail and Rudha Bholsa presents a magnificent section, largely of the Dolomitic Group. The rocks run out to sea in long 'scars', in which junctions and structure can be seen on wave-worn surfaces with exceptional clearness. Starting in Bagh an da Dhoruis, a mile south-west of Rhuvaal lighthouse, the Main Quartzite at the 'Cave of Two Doors', from which the bay takes its name, is faulted against the Dolomitic Flags: these extend for a mile westwards in a beautiful little synclinorium, at first sheared and contorted from the south-east, thereafter from the south-west, and finally from the west, near Port a'Chotain, where masses of fault-breccia bring in the Bowmore Flags, striking south-eastwards against the fault. Port a'Chotain consists entirely of varied Bowmore Flags, including some contorted beds of interbedded white siliceous and grey argillaceous types in laminæ a few millimetres thick, vividly reminiscent of a contorted gneiss. They extend along the coast for nearly 200 yards, and are covered by the White Quartzite, both dipping 20° south-westwards. The junction is washed bare, quartzite often overhanging it. I have inspected about 40 yards of it (there is probably more), and there can be no doubt of perfect conformability. The passage only occupies a few inches.

The White Quartzite (with occasional exposure of the Main Quartzite) continues south-westwards for 320 yards to a point a little less than 300 yards east of an important boundary-fence which follows the line of a streamlet running northwards to the sea. Here a great fault-breccia, in places over 30 yards thick, comes in, intersected by a basalt-dyke. The fault brings in at once massive green-grey arkoses of the Portaskaig Beds, which continue for 150 yards. Any doubt about the identification is set at rest by the occurrence 130 yards east of the fence of a band with boulders of quartzite and nordmarkite, the latter measuring up to more than 20 cm. in length.[1]

Some 90 yards east of the fence the junction of arkose with a dolomite is seen in the beach. This junction is well exposed, and seems normal, although there is much red staining. The unstained dolomite is cream-coloured, sandless, and often pyritous. It resembles the dolomite-boulders of the Portaskaig Conglomerate, which are probably derived from it. It passes into Dolomitic Flags, which in their turn pass into Bowmore Flags a few yards west of the fence. The latter are exposed for about 40 yards.

[1] The Geological Survey, though describing the conglomerate-band, colours both quartzite and arkose as continuous quartzite; and Mr. Bailey appears to accept that view (4, p. 149). The rocks seem to me quite distinct.

For 700 yards west of this point the rocks consist wholly of the folded-up dolomitic group, mainly Dolomitic Flags. Some 300 yards west of the fence the cream-coloured dolomite occurs again, and 50 yards farther on come 30 or 40 yards of Bowmore Flags. So far as I could see, in a somewhat hasty examination of this portion, the junctions were everywhere normal and gradual. The Bowmore Flags come on again west of Port an-t Sruthain, where the passage into the Dolomitic Flags is well seen. All the usual varieties are present, and also the gneiss-like contorted type mentioned above. The dip is 50° westwards, and the outcrop 35 yards broad; then the White Quartzite appears. As Mr. Bailey has pointed out (4, p. 149), the junction can be seen in the cliff; but it is better examined in the beach, where the quartzite is plastered against a long stack of Bowmore Flags. I noted 8 feet of bare washed junction, cleaved, but in all respects like that observed elsewhere. The White Quartzite is followed as usual by the Main Quartzite, which constitutes the remainder of the northern coast.

North-east.—Inland, in the north-east of the island, the rocks in the areas about Margadale and north-west of Loch Staoisha, where the Dolomitic Group is widespread, are on the whole poorly exposed; but nothing has been found to contradict the results obtained elsewhere.

South.—Turning now to the south-eastern limb of the main fold of Islay, we find that the Portaskaig Beds[1] appear generally to be in direct contact with the White Quartzite; but, in one place at least, the Dolomitic Group intervenes. This is on the upper part of Beinn Bhan (south-eastern corner of the index-map, fig. 1, p. 76). The summit-ridge is entirely built of the White Quartzite, from the gleaming masses of which the mountain derives its name (bhan = white). Near three little lochans west of the summit, the White Quartzite is succeeded on the north-west by large exposures of rather siliceous Bowmore Flags, deeply bleached, but with unaltered cores; next there is a long band of sheared, dark-green, argillaceous rock, followed by bleached flags more finely bedded than those first mentioned. Continuing northwards, the Dolomitic Flags appear near and west of the western corner of the largest lochan, and are followed by coarse green arkoses of the Portaskaig Beds. The whole are dipping 35° to 40° north-westwards. There is no evidence that the Dolomitic Group has thinned in any way; the Bowmore Flags of Beinn Bhan appear to be at least as thick and varied as those in the north of the island.

[1] The Portaskaig Beds are more continuous along the south-eastern outcrop than might be supposed from the Geological Survey map. Much of them is non-pebbly, and has been coloured as quartzite.

VII. The Apparent Reversal along Islay Sound.

Thus all evidence from places where the relations of the Bowmore Flags to the White Quartzite can be seen or inferred when traced along the line of strike, points to conformity and a position between the quartzite and the Dolomitic Flags; while the northern coast-section indicates a passage of the Dolomitic Flags on their other margin into pure dolomite.

But, in certain faulted strips along the coast of Islay Sound, between Bonahaven and Portaskaig, where the succession can be followed only across the strike, there appears locally to be a reversal of the succession within the Dolomite Group. Here the Bowmore Flags (or rocks lithologically identical) come up between the Dolomitic Flags and the Portaskaig Beds; the datum-line, however, the White Quartzite, is nowhere seen.

It has already been pointed out that, on the northern coast, the Portaskaig Beds are in contact with a dolomite at one end of the Dolomitic Group; whereas, a few miles south of Portaskaig, they are in contact with the White Quartzite, and thus must have overlapped both the Dolomitic Flags and the Bowmore Flags. Between these two points, if the ground were clear, the Portaskaig Beds would be seen in contact with various parts, first of the Dolomitic, and then of the Bowmore Flags, so that in these strips one of the stages in this erosion must be encountered.

The section (fig. 2, p. 82) is drawn along the coast from Bonahaven to Portaskaig, $2\frac{1}{4}$ miles. The fault at Bonahaven brings Quartzite against Dolomitic Flags dipping north-north-westwards with some dolomite, at Rudh'a'Mhill, close to the village.[1]

The Dolomitic Flags are then developed for 500 yards, dipping 35° a little west of north, when the Bluish Quartzite comes in, followed by thin Dolomitic Flags, passing into Bowmore Flags, of which there is a huge face in the cliffs of Creag Mhor. The arkoses of the Portaskaig Beds come on 100 yards north of Con Tom and, occasionally coarsely conglomeratic, form the coast for a mile. At a point 100 yards north of a Na Feamindean, a thick fault-breccia brings on again Dolomitic Flags with some dolomite. Flags follow for 300 yards, when the Bluish Quartzite appears, followed by 150 yards more of Dolomitic Flags and 90 yards of Bowmore Flags, under which the arkoses rise north of the Caol Ila distillery. The Portaskaig Beds continue along the coast for about 2 miles.

Thus there is apparently a complete reversal of the sequence previously determined within the dolomitic series. But the considerations above mentioned show that this was to be expected, and that the explanation is probably as represented in fig. 2. The unconformity has been caught in a compound anticline, the upper part of which has been eroded away.

The Bonahaven-Portaskaig section is the most conveniently

[1] Off Rudh'a'Mhill the strike seems to swing right round, certain beds dipping slightly north of east, so that they are presumably on the arch or trough of a fold with an eastward pitch. Unfortunately, I did not at the time realize the interest of the point, and I have not since had an opportunity of verifying the fold, or of comparing the dolomite in its core with the dolomite of the northern coast.

accessible, and (at first sight) the clearest, section of the dolomitic series of Islay; it has naturally been taken as an index, with somewhat unfortunate results. I venture to suggest that in highly folded country a sequence with one end missing, determined by a traverse across the strike, cannot be accepted with confidence. I have failed to find any other evidence for the Geological Survey view that the sandy shales and flags (that is, Bowmore Flags) occur on two horizons.

[It is true that that view is not definitely disproved by the foregoing considerations; but I suggest that, on facts known at present, the hypothesis of a second flaggy horizon is unnecessary. Its occurrence would not affect the conclusions of this paper.—*J. F. N. G., February 16th, 1924.*]

VIII. Stratigraphical Order.

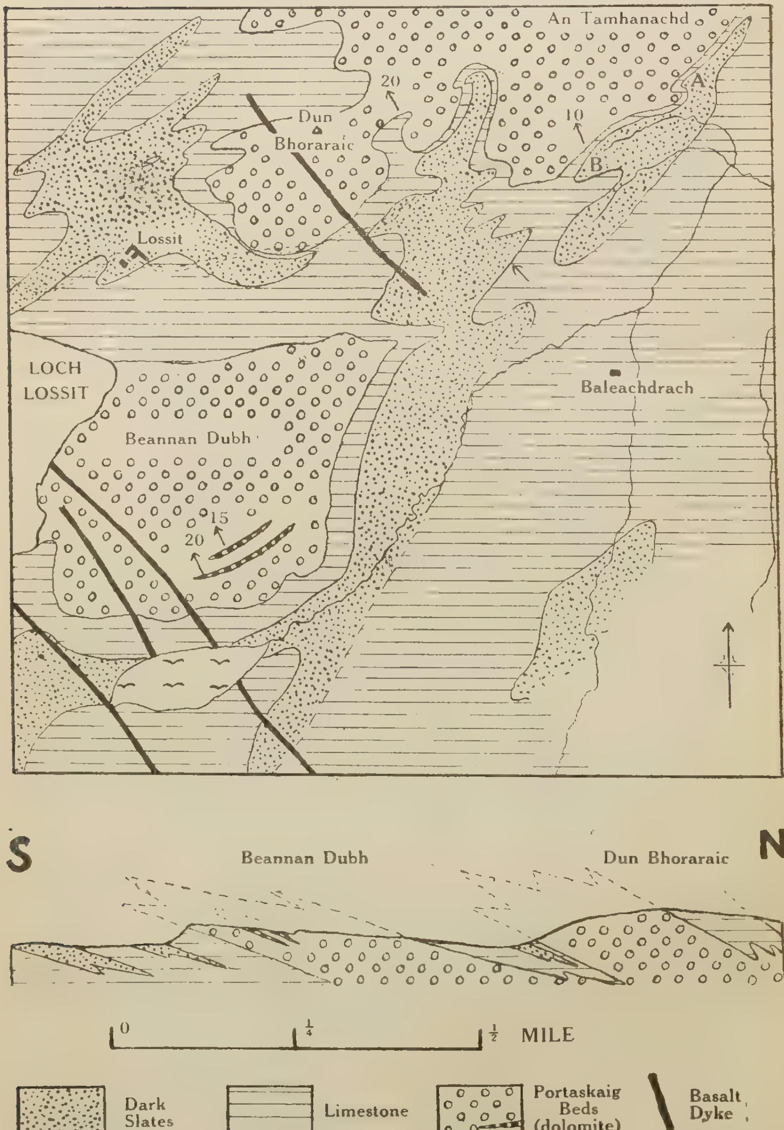
Two lines of evidence have already been noted for placing the Portaskaig Beds above the dolomitic series and the Islay Quartzite, and it is desirable next to go more closely into a third line, which has only been touched upon slightly in connexion with the Tallant area: namely, the attitude of the folds.

The folding in Islay, as indicated by the puckers, minor folds, shears, and cleavage, has been hitherto little studied; the best material available is Mr. Bailey's valuable map of the dips (4, pl. xii) which shows that the island may be divided into four sectors, two characterized by south-eastward and two by north-westward dips, with local variations. In the case of the three northernmost sectors I have verified that, as might be expected, the shears and contortions are in directions contrary to the dips. On the principles governing folding, the larger folds may be expected to conform in attitude to the smaller.

The structure is particularly clear in the district between Loch Lossit and Islay Sound, of which I give a detailed map (fig. 3, p. 96). The area is one of low relief: the highest point, the summit of Dun Bhoraraic (more usually called Dunlossit), being only 316 feet above the surface of Loch Lossit; and when such slight relief only is present, it is advisable to exercise caution in reasoning that the rocks of the higher parts overlie those of the lower levels. For, in highly folded country, whatever the order of superposition, the more resistant rocks will, owing to differential erosion, commonly be found on the higher ground. The Conglomerate is far more resistant than the Limestone or Dark Slates, the other members of the sequence present. Nevertheless, in the neighbourhood of Loch Lossit the position of Portaskaig Conglomerate on the tops of Dun Bhoraraic and of Beannan Dubh, with limestone in the lower slopes, has been held, both in the Geological Survey Memoir (3, pp. 45–46) and by Mr. Bailey (4, pp. 143–4), to be proof that the conglomerate is lying almost flat upon the limestone, despite the constant north-north-westward dip. I believe that this view is mistaken.

Sheet 27. S.E.
N. 55°49'. W. 6°8'.

Fig. 3.—*Map and section of the country east of Loch Lossit.*



The nature of the folding is best seen in the Calcareous Passage-Beds between the Limestone and the Dark Slates, which are repeatedly exposed. At two points (see also photograph, Pl. V, fig. 1) these beds are seen to be thrown into compound folds overturned southwards, with axial planes dipping from 5° to 30° north-north-westwards.

The Limestone can be traced from the north-eastern corner of the map, underlying the Portaskaig Beds structurally, and dipping usually 10° to 20° north-north-westwards, to the vicinity of Lossit Farm. The outcrop is for the greater part demonstrably narrow, not more than 50 yards broad; where it crosses the track east of Lossit, the Limestone is thinned down to about 12 feet in thickness. In places the rocks are greatly sheared, even pulled into lenticles.

Next to the Limestone there is then on the south-south-east a discontinuous outcrop of Dark Slates, followed by an outcrop of Limestone varying in breadth from 150 yards to over half a mile.

Clearly, in accordance with the usual rule of the thinning of the inverted limb in sharp overfolding, the pulled-out narrow belt of Limestone, when compared with the broad southern outcrop, must be on an inverted limb of a major fold; therefore, the Portaskaig Conglomerate underlay the Limestone when folding took place, and is brought up on Dun Bhoraraic by an anticline. It follows that Beannan Dubh is also anticlinal. Similar, though less marked, structure appears next this latter mass of conglomerate, the outcrop of Limestone bordering its southern and eastern sides being narrow compared with the extensive stretches found beyond the succeeding belt of Dark Slates.

I regard therefore Beannan Dubh and Dun Bhoraraic as compound isoclinal anticlines dipping about 20° north-north-westwards. This interpretation will be confirmed, if inverse repetition can be proved inside either of them.

The 1-inch map shows two small lenticular exposures of dolomite in the Portaskaig Beds of the south of Beannan Dubh,[1] and Mr. Bailey (4, p. 143) has drawn particular attention to one of them, as he considers that a breccia in it, seen overlying dolomite, proves erosion of the latter, and that the section is, therefore, 'right way up'. The section, which forms a small escarpment, is exceptionally clear and interesting; it is as follows:—

Massive sandstone.

Breccia of dolomite-fragments in dolomitic sand. Usually 2 to 3 feet thick.

Cream-coloured dolomite, usually about 3 feet thick, but with a maximum of 8 feet. It thins out at each end, the exposure being 270 yards long.

False-bedded shaly sandstone presenting a ripple-marked appearance. 12 to 15 inches.

Massive sandstone showing traces of bedding.

The dip is from 15° to 20° north-north-westwards.

[1] This part of the elevation is properly known as Beannan Buidhe (Yellow Hills) in allusion to the rusty-orange weathered surfaces of the conglomerate, which is somewhat dolomitic. But it is convenient to retain the nearest name on the 1-inch map.

The second lenticular exposure shown on the 1-inch map lies north-north-west of, and parallel to, the first, at a distance of 60 yards. It repeats the same, but in reverse order:

Massive sandstone (only seen on the east).

False-bedded shaly sandstone, with ripple-marked appearance. 9 to 12 inches.

Cream-coloured dolomite, maximum thickness $4\frac{1}{2}$ feet. Exposure about 150 yards long.

Breccia of dolomite-fragments in dolomitic sand. 3 feet.

Massive sandstone.

The true dip is rather difficult to obtain, but is about 15° north-north-westwards.

Obviously, one band is the other reversed; both are sections of the same doubled-up lenticle. It would be difficult to obtain better evidence of large-scale isoclinal folding. Is the character of the fold demonstrable?

The breccia is of a peculiar type. On the weathered surfaces it is obvious that the fragments of dolomite, from 1 to 50 cm. long, are angular, with a strong tendency to rectangular sections, two or three times as long as broad. The shape of the fragments is better seen when pieces of the breccia are roughly rubbed down. Their habit in section, as elongated rectangles or truncated wedges, is then very plain; re-entrant angles, especially at the end of rectangles, are not uncommon; and, occasionally, flat bits are curved. Such shapes are characteristic of only one kind of deposit, namely desiccation-breccia.[1]

There must have been a depression among the sandbanks, in which, as on a recent shore, fine mud was deposited after the sea had retired. The pool dried, and the mud cracked up, to be buried in mixed sand and mud when the water next rushed in. The process would be repeated until the depression was filled, breached, or shut off.

No deduction as to the order of deposition can well be made from such a breccia, and I failed to obtain clear results from some accompanying sun-cracks; there are, however, certain other structures which seem to afford a clue. About 50 yards from the western termination of the more southerly outcrop the false-bedded sandstone, which elsewhere lies evenly along the strike-face of a little escarpment, rises into a series of arches in the dolomite, here at its thickest, at one point almost completely cutting it out. These arches have evidently nothing to do with the folding, and seem to be sections of domed hollows in the dolomite. The only explanation that I can offer is, that they mark a solution-hollow in the dolomite, in which case the section is inverted. (It may be observed that swallow-holes are common in the dolomitic beds of Northern Islay.)

A similar hollow, but on a smaller scale, occurs at the top of

[1] See C. D. Walcott, Bull. U.S. Geol. Surv. No. 134 (1896) p. 34; J. E. Hyde, Amer. Journ. Sci. ser. 4, vol. xxv (1908) p. 400; and G. Barrow, 'Geology of the Country around Lichfield' Mem. Geol. Surv. 1919, pp. 47–48.

the more northern band of dolomite, also at its thickest part.[1] This hollow is about 15 inches deep, the false-bedded sandstone turning down into it at an angle of 70°.

Since the more southern band is the inverted one, and the folds are overturned south-south-eastwards, the conglomerate must contain a true anticline. I could find no evidence for further inversion between the dolomite-bands and the junction of the Portaskaig Beds with the Islay Limestone, and I conclude that the Limestone, stratigraphically as well as structurally, overlies the Portaskaig Beds.

IX. Conclusions.

The chief conclusions of this paper are:—

(1) The 'Bowmore Sandstone' of the Survey consists, in reality, partly of the Portaskaig Conglomerate and its associated arkose-sandstones; and partly of the flaggy passage-beds (Bowmore Flags) between the Islay Quartzite and the Dolomitic Flags.

(2) The 'Loch Skerrols Thrust' has no existence.

(3) The Bowmore Flags are strictly conformable to the white edge of the Islay Quartzite (White Quartzite).

(4) Five lines of evidence converge to prove that the Limestone structurally and stratigraphically overlies the Portaskaig Beds, which in their turn overlie the Dolomitic Group and the Islay Quartzite. These are:—

- (*a*) Attitude of false bedding at the edge of the White Quartzite.
- (*b*) Solution-hollows in the dolomite-lenticle of Beannan Dubh.
- (*c*) Erosion at the base of the Portaskaig Beds, which may rest on any member of the Dolomitic Group, or on the White Quartzite.
- (*d*) The frequency of dolomite-boulders, and the absence, or at least great rarity, of limestone-boulders in the conglomerate.
- (*e*) The attitude of the folds.

(*a*) and (*b*), as relating to particular beds in a highly folded sequence, are not of much importance; but (*c*) and (*e*) seem conclusive.

(5) The structure is, therefore, synclinal, not anticlinal.

(6) Only one system of folding is required to explain this structure. In Islay this system consists of a series of synclinoria and anticlinoria with isoclinal folds, the axial planes having a low dip. These folds have amplitudes varying from a minute fraction of an inch in the soft beds to several thousand feet.

It will be obvious that, if these conclusions are justified, the supposed asymmetry of the Loch Awe Syncline, upon which a theory of the structure of the South-West Highlands has been founded, can no longer be accepted. But inferences applicable to the mainland are not dealt with here.

[1] The thickest part presumably represents the deepest part of the pool, above which a depression in the dried infilling is to be expected. Solution would start at a depression.

My work has been greatly facilitated by access to the collections of the Geological Survey, and I have particularly to thank Mr. E. B. Bailey, who saved me much time and trouble by copying part of the 6-inch map for me, and has pointed out some omissions and obscurities in my manuscript.

X. References.

1. J. Thomson, 'On the Geology of the Island of Islay' Trans. Geol. Soc. Glasgow, vol. v (1873–76) 1875, p. 200.
2. 'The Geological Structure of the North-West Highlands of Scotland' Mem. Geol. Surv. 1907.
3. B. N. Peach & S. B. Wilkinson, 'The Geology of Islay' Mem. Geol. Surv. 1907.
4. E. B. Bailey, 'The Islay Anticline (Inner Hebrides)' Q. J. G. S. vol. lxxii (1916–17) p. 132.

EXPLANATION OF PLATES V & VI.

Plate V.

Fig. 1. Overfold in the Calcareous Passage-Beds, south of An Tamhanachd (Eastern Islay), looking north-eastwards.

2. Bowmore Flags, north of Rudha Buidhe, Loch Indaal (Islay), looking north-eastwards.

Plate VI.

Geological map of the country about Bridgend (Islay), on the scale of 2 inches to the mile, or 1 : 31,680.

Discussion.

The Secretary read the following contribution to the Discussion from Mr. E. B. Bailey:—'I have had the privilege of reading this paper in MS., and seeing the Author's slices from Blackrock and Tallant. I believe that he has established the exceedingly important point that, at any rate, somewhat similar nordmarkitic assemblages have contributed material to the Blackrock Grit and the Portaskaig Conglomerate respectively. In this matter, particular weight attaches to the Blackrock specimens, since those from Tallant have been collected in an angle between a fault and a thrust (according to previous observers), wherefore their authenticity as representative of the Blackrock Grit may be questioned. I am, however, satisfied that the Tallant specimens belong to the Blackrock Grit (or, at any rate, to the Bowmore Sandstone which includes this grit): certainly, they closely resemble the grit in its typical occurrence; while, in my opinion, they cannot be matched easily, if at all, in the Portaskaig Conglomerate.

'The Tallant slices contain well-marked nordmarkitic pebbles; and the Blackrock slices show what appear to be smaller examples, along with much crystal débris of closely similar type.

'Dr. B. N. Peach has, for several years, urged in conversation that erosion of the same nordmarkitic assemblage, as is represented

Fig. 1.—*Overfold in the Calcareous Passage-Beds, south of An Tamhanachd (Eastern Islay), looking north-eastwards.*

Fig. 2.—*Bowmore Flags, north of Rudha Buidhe, Loch Indaal (Islay), looking north-eastwards.*

J. F. N. G. photo.

Sheet 27, 1" to 40.

Margin Sheet 19 ↓ Sheet 27.

MAP OF THE COUNTRY ABOUT BRIDGEND (ISLAY), on the scale of 2 inches to the mile, or 1: 31,680.

by boulders in the Portaskaig Conglomerate, was also responsible for much of the material of the Torridonian arkoses of the North-West Highlands. The Author's observation has given fresh life to this suggestion, for the Blackrock Grits have long been compared with the Torridonian arkoses of the North-West. Accordingly, I have followed up this point, and I can confirm the fact that, in their mineral-assemblage of quartz, microcline, and perthitic potash-soda felspars, the arkoses of the North-West (slides 6188, 3715–16, 2263–64 of the Geological Survey) reproduce the main features of the Blackrock Grits. Moreover, one of the sliced felsite-pebbles from the North-West actually shows in its phenocrysts the characteristic soda-rich alkali-felspars of the nordmarkites (6188). This slice is unsheared, and it reveals a further resemblance to the Blackrock Grit in a suggestion of wind-rounding of some of the quartz-grains among which the felsite-pebble lies. I can only say that Dr. Peach's hypothesis, viewed in the light of the Author's recent discoveries, is immensely strengthened.

'As indicated below, I do not feel inclined to follow the Author in his correlation of the Blackrock Grit and Portaskaig Beds, which latter include my Lower Fine-Grained Quartzite and Portaskaig Conglomerate (Q. J. G. S. vol. lxxii, 1916–17, pp. 142, 147). The only part of his Portaskaig Beds which seems to me to resemble the Blackrock Grit is a well-known conglomeratic zone towards the top of my Lower Fine-Grained Quartzite.

'The Author claims that it is a misnomer to speak of my Lower Fine-Grained Quartzite as quartzite at all. In his full account, he points out that some of this group is conglomerate. The same fact has already been stated by the Geological Survey, who have separated the conglomerate-bands, more particularly, on their MS. maps. In my own map (*op. cit.* pl. xii), I have published the conglomeratic outcrops rather more fully. There is, in this direction, nothing new in the Author's records.

'It is, therefore, only in regard to the naming of the non-conglomeratic part of the group that there is any difference of opinion. The Author describes it as an arkose with more than 10 per cent. of felspar. I have spoken of it on the Sound of Islay as "pure, though slightly felspathic, vitreous" quartzite (*op. cit.* p. 147). On turning to Dr. C. T. Clough's manuscript notes on the fullest coast-section, I find that he refers only three times to exposures intervening between the conglomeratic zones just mentioned and the Portaskaig Conglomerate below, and each time he uses the descriptive words "white quartzite."

'On the other hand, when the Author claims that, even apart from its conglomeratic associates, my Lower Fine-Grained Quartzite is distinguishable from my Upper Fine-Grained Quartzite, I agree. In reference to the latter, I have already stated that it is whiter probably than the Lower Quartzite (*op. cit.* p. 149).

'The Author goes farther. He says that he cannot draw a dividing line between my Lower Fine-Grained Quartzite and the

Portaskaig Conglomerate. This is surprising, for a dividing line was drawn by Dr. Clough & Mr. S. B. Wilkinson throughout Northern Islay, and was published before I visited the island. I scrutinized it carefully along its entire course, and accepted my predecessors' work with trivial emendations. If no line had been drawn on the maps, I should certainly have inserted one, so as to reproduce a distinction which seems to me quite obvious in the field.

'I am amazed to find that the Author regards the coarser parts of my Bowmore Sandstone as indistinguishable from his Portaskaig Beds (my Portaskaig Conglomerate and Lower Fine-Grained Quartzite combined); and equally surprised to find him correlating the fine parts of Bowmore Sandstone with rocks which occupy two distinct positions in my Dolomitic Flag Group. In this latter connexion, the Author claims that the rocks of the Bowmore foreshore are identical in detail with the rocks intervening between my Lower Fine-Grained Quartzite and a conspicuous minor quartzite-band cropping out on the Portaskaig coast, and distinguished as the "Pipe Rock" in the Geological Survey Memoir. If this be so, there must be something very seriously wrong with the descriptions that I have given of these two exposures (*op. cit.* pp. 138, 147). These descriptions were written face to face with the rocks. They had no ulterior motive, for it never occurred to me that anyone would think of comparing groups so obviously different. I have a right to claim that the reader be informed in what particulars my descriptions err.

'The Author adopts the unjustifiable attitude that, when he cannot distinguish between two rock-groups, these must be stratigraphically identical, even when he has to admit that their associates are different. This leads him to recognize with confidence unconformities of which there is no other hint in nature.

'The Author holds that, having correlated the Bowmore Sandstone on the one side of the Loch Skerrols Thrust with two zones cropping out on the other, he has shown that the thrust is non-existent. He puts aside the obvious shearing which led Dr. B. N. Peach & Dr. J. Horne originally to recognize this thrust. More important still, he does not realize that, even according to his own correlations, the Loch Skerrols Thrust (as mapped by the Survey) separates two districts of entirely different geological complexion. East of the line, his supposed equivalents of two divisions of my Bowmore Sandstone occur as minor groups in a well-marked variegated sequence; they are separated in most of their outcrops by other members of the series, although locally the Author claims that they come together as a result of pre-Portaskaig erosion; everywhere, singly or combined, they maintain an appearance of very moderate dimensions. West of the line, however, they invariably come together, and assume an apparent thickness of many thousands of feet!

'Structurally, the Author's work is representative of a great deal that has been published in regard to the Scottish Highlands. Each

anticline is treated as a synclinorium, each syncline as an anticlinorium. Until recently, this type of structural outlook has been almost restricted to Scotland, where it originated through the publication of the "Secret of the Highlands", a paper in which Prof. Charles Lapworth introduced many British readers to the double folds and fans of Albert Heim's philosophy. The Highland School dealt with a region of low relief, which freed them from many of the responsibilities of the Alpinists; and, in their hands, buckling and double folding presently reached limits which far exceeded anything that Heim had dreamt of. Meanwhile, Heim himself was busily correcting his old mistakes; wherefore the theories, of which the Author is a confident exponent, are now in the curious position of having no roots.

'I have myself given a full account of the structure of Islay, in which every rock is trusted to be doing what it is seen to be doing. Exposures are good, and the story told by them is absolutely consistent. It seems to me that the Islay Anticline can only be re-interpreted by a man who is ready to admit that Nature is designed to deceive geologists. The double folds of the Author's hypotheses outrival the famous Glarus example, and even surpass those involved in recent re-interpretations of Mullfjället. As a concrete criticism, I may draw attention to the Author's section from Portaskaig to Bonahaven. His interpretation involves large-scale movement of so special and differential a character, that one wonders at his daring when he reads into it the effects of a minor unconformity. My own explanation of the difficulty is that the Author has misread his stratigraphical sequence.

'The Author's description of Beannan Dubh stands on a different footing, for it includes a new observation, which, if maintained, seriously weakens my interpretation of the original order of deposition. I have, of course, examined the exposure cited, and, although specially on the outlook, I did not see the particular appearance of inverted solution-erosion to which he draws attention. I surmise that the appearance is capable of some other explanation than that put forward by the Author; but nothing else than fresh examination can settle such a point.'

Mr. G. Barrow thought that the Author could have more easily proved his main point by starting from the base of the Quartzite (the Central Highland Quartzite) which occurs along nearly the whole of the south-eastern side of Islay, a little inland. Mr. Wilkinson gives the evidence that this is the base in great detail, the lowest part of the rock being often black and at times containing slabs of underlying material (now a graphitic phyllite) fully a foot long. Proceeding inland across the broad outcrop, one meets with alternations of pebbly quartzite and massive quartzite until the other margin is reached: this is fine-grained and white; it is, in fact, the typical white top of the quartzite which occurs right across the Highlands, and is so well seen on the coast at Portsoy. This margin, although everywhere of the same nature,

is not apparently noted by Mr. Wilkinson; but he clearly states that the conglomeratic material, which he correlates with the Portaskaig Conglomerates, and which occurs really next to or close to this margin, is quite unlike the conglomeratic material actually inside the true base of the quartzite. Although he shows that this white margin must be the opposite side or top of the quartzite, he rejects this view solely because the limestone is seen lying under this margin. But, in the numerous quartzite-mountains in the centre of this country (Blair Athol, Braemar, etc.), the limestone overlies the white top on the south-eastern side of the mountains, and invariably underlies it on the north-western side; the dip is isoclinal throughout. Mr. Wilkinson's view is based upon evidence that has no value in determining the order of succession.

Thus the great central group of beds in Islay, consisting of the Limestone Boulder-Bed (Portaskaig Conglomerate), Dolomitic Series, and the flags described by the Author must overlie the Quartzite. North-west of this group the white top of the quartzite comes up again, followed by the main mass of the rock, and thus the Limestone and the associated beds must lie in a syncline, though of a complicated character.

North of Loch Skerrols, the 'fine white margin' is often seen, repeated by minor folds; it is here absolutely identical with the same margin of the Quartzite at Portsoy on the east coast. It is not merely fine and white, it exhibits those curious fine black lines on its exposed face, due to the presence of films of heavy minerals, which show perfectly the false bedding in the rock. In contact with this are the typical thin flags ('Honestones' of the speaker), which thicken slightly to the south and undoubtedly occur on both sides of the supposed thrust, as the Author has shown. These flags become much thicker in the Bowmore area, and present field-characters, identifying them with the (more crystalline) Moine gneisses which form the dominant component of roughly 1000 square miles of the Highland Area, and occur at no great distance south-east of the Moine Thrust. The Author had shown lantern-slides of these gneisses to prove their identity with the Bowmore flagstones.

The statement that the Loch Skerrols Thrust has no existence is not really surprising. The same is true of the boundaries of the supposed inliers of Lewisian Gneiss in the so-called Dalradian or Newer Gneisses in the area south-east of the Moine Thrust. These boundaries, whether they be called thrust-planes or unconformities, do not exist, for the inliers of Lewisian Gneiss do not exist. It has become clear that these areas fall strictly into their proper places in the thermal zoning of the Highland rocks.

The AUTHOR, in reply, regretted that there had not been more criticism. He then read the following reply to Mr. Bailey's criticisms:—'I much regret having to differ from so brilliant and open-minded a geologist, but am glad that Mr. Bailey accepts my identification of the nordmarkite-suite in the Blackrock Grits. I am content to leave the logical deduction from the lithological evidence to the reader.

'I am indifferent to nomenclature, so long as those who settle such high matters do not confuse rocks of different composition which they choose to call by the same name. With regard to my identifications, I prefer evidence to authority, and distrust the somewhat dangerous experience which can draw distinctions that cannot be defined. I have stated the evidence upon which I rely. As Mr. Bailey asks that the reader may be informed in what particulars his descriptions of the siliceo-argillaceous flags err, I may say that they do not take enough account of the variability of appearance in a bedded argillaceous sandstone due to varying proportions of constituents. For instance, Mr. Bailey's description (*op. cit.* p. 138) of the Bowmore-Laggan section as "compact, hard, fine-grained sandstone, weathering with brown surfaces, but grey on a fractured face.... The rocks are extremely homogeneous, and therefore the bedding is very faintly marked" applies to many parts of that coast; but, as the specimens and photographs exhibited show, not to others, such as Eilean an Droighinn, which is better fitted by Mr. Bailey's later wording (*op. cit.* p. 147). On the other hand, the above-quoted description also applies well to parts of the flags on the Portaskaig coast, as developed at Carraig Artair and Creag Mhor. Therefore, I accept both Mr. Bailey's descriptions, so far as they go. I must however demur to Mr. Bailey's view that the districts "separated" by the supposed thrust are of entirely different geological complexions. The only difference is the breadth of the Bowmore Flag outcrop, which is comparable to the change in the breadth of the Limestone outcrop north-east of Beannan Dubh in a distance of 100 yards. It would seem as reasonable to insert a thrust along the western edge of the Weald, because the Chalk west of it has an outcrop 30 times as broad as it has on the Hog's Back. I can see no reason why we should expect the Tertiary structures of the Alps to be repeated in the Highlands, or why the kaleidoscopic theories of Alpinists should be treated as firmer soil than the work of Charles Lapworth and of our American colleagues. The folds of my sections are puny affairs, compared even with Mr. Bailey's interpretation of Ben Udlaidh, still more with his mighty nappes. I take this opportunity of saying definitely that, as a result of my study of the published maps, I do not believe that the supposed slides and nappes of the South-West Highlands have any real existence; but such explanations are necessary, if sequences are to be taken from sections like those at Portaskaig.

'Finally, I wished to point out that, by deduction from a hypothesis (which, at the time, I regarded as doubtful) I was able from London to put my finger on the spot in Scotland where the igneous suite of the Highland Boulder-Bed could be found in supposed Torridonian; and I obtained the nordmarkite on my first morning, a few minutes after starting to look for it. If that hypothesis is wrong, and the eminent geologists mentioned by Mr. Bailey are right, it is surprising that they, who have spent more days in Islay than I have hours, and possess a thousand times my knowledge of the Highlands, should not have anticipated me.'

6. *The* Igneous Rocks *of the* Tortworth Inlier.

By Prof. Sidney Hugh Reynolds, M.A., Sc.D., F.G.S. (Read November 7th, 1923.)

[Plates VII & VIII.]

Contents.

I. Introduction.

In a paper published in 1901 [1] by the present writer, in collaboration with Dr. C. Lloyd Morgan, an account is given of the igneous rocks of the Tortworth Inlier, the divergent views of previous writers as to the contemporaneous or intrusive character of the rocks are summarized, and the occurrence of fossiliferous calcareous tuffs is proved, leading to the conclusion that the associated 'trap'-rocks are lava-flows of Silurian age. The exposures of 'trap' in the neighbourhood of Woodford and Middlemill are considered to belong to the lower of the two trap-bands.

A second paper by the present writer, in this case in collaboration with Dr. F. R. Cowper Reed, published in 1908,[2] was concerned only with the fossiliferous Silurian rocks. The work, however, led to the conclusion that the trap of Woodford and Middlemill does not belong to the lower band, but is really part of the upper band shifted northwards by a fault (see fig. 3, Q. J. G. S. vol. lxiv, 1908, p. 518). Further information relative to the igneous rocks, obtained when working at the above paper, was published in 1908 in the report of a committee of the British Association, appointed to investigate the pre-Devonian rocks of the Mendips and Bristol area.[3] In this report reason is given for doubting whether the lower trap-band may not, after all, be intrusive.

II. The Lower 'Trap'-Band.

The rocks are exposed:—

(1) by the stream about 300 yards south-east of Charfield railway-station;
(2) in two old quarries, one east and one west, of Whitehall Villa, Damery;
(3) in Damery Quarry;
(4) at various points in Michael (Mickle) Wood.

The rock at all these localities is very uniform in general

[1] Q. J. G. S. vol. lvii, pp. 267–84.
[2] *Ibid.* vol. lxiv, pp. 512–45.
[3] Rep. Brit. Assoc. (Dublin) 1908, pp. 289–91.

appearance, both in hand-specimens and in thin sections, and consists in the main of felspar-laths 5 or 6 times as long as they are wide. There are no felspar-phenocrysts, nor included patches differing in grain from the bulk of the rock, nor quartz-xenocrysts, all of which are characteristic of the upper band. The ground-mass, though sometimes (134) [1] slightly glassy, shows this feature much less than in the case of the rocks of the upper band.

The felspars [2] in almost every case were probably originally medium labradorite. Occasionally, as in a rock from Damery Quarry, the felspar remains labradorite; but, in the great majority of cases, the labradorite has been wholly or partly replaced by a more acid felspar. Thus, in a rock from Charfield Green (5), the larger labradorite-crystals have strings and patches of albite occurring throughout them, and there are also acid replacements and additions at the margin. In a rock from the quarry west of Whitehall Villa (140) the labradorites have not only been much albitized, but are frequently edged with oligoclase. One of the rocks from Damery (17) is highly albitized, as is also one (129) from Mickle Wood. On the other hand (18) from Mickle Wood shows replacement of labradorite by oligoclase. A rock from the old quarry east of Whitehall Villa (30 A) shows the felspar strongly zoned: the more basic felspar has been decomposed, but the more acid oligoclase-andesine is fresh, and there has been little or no albitization. One of the rocks from Damery (120) contains felspar of slightly more acid character than usual, mainly andesine to acid labradorite, there has been some albitization, with the production of albite-oligoclase. Albitization is certainly a general feature of these rocks, and in this connexion attention may be drawn to the presence of 5·13 per cent. of soda in the partial analysis of a rock from Damery quoted below.

Pseudomorphs after olivine, though never very plentiful, are characteristic of all the rocks of the lower band. The pseudomorphs are generally in chlorite, sometimes in serpentine, rarely in calcite. Rhombic pyroxene, though subordinate, is always present in the form of small grains filling the interstices between the felspar-laths. The rhombic pyroxene may be partly fresh (5), but is as a rule replaced by bastite-pseudomorphs (18, 134). Small chloritic (130) patches probably represent pyroxene. Many of the rocks are stained with ferric oxide, and grains of magnetite are more plentiful than in the rocks of the upper band, though less plentiful than in most normal basalts.

Mr. E. G. Radley has determined the following silica and alkali percentages:—

		SiO_2.	K_2O.	Na_2O.
E 4.	300 yards south-east of Charfield Station.	52·60	1·06	3·62
E 120.	Damery Quarry	47·86	2·57	5·13
E 129.	Mickle Wood	55·42	—	—

[1] Numerals in parentheses refer to the numbers given in § 4, Key to Localities, p. 110.

[2] The following account of the felspars is entirely based on notes kindly supplied by Dr. Herbert H. Thomas.

The rocks are not, as a rule, amygdaloidal, though this feature is seen at the base of the Damery mass and in some rocks from Charfield Green (5).

The Damery and Mickle Wood 'traps' contain in places many small pieces of sandstone. This is very little modified at the contact; but the narrow tongues of 'trap' which penetrate it, and the numerous cracks which radiate from the margin of the 'trap' through the sandstone without replacing its banding (see Pl. VIII) suggest high pressure, and are consistent with the view that the lower 'trap'-band is intrusive. The rocks of the lower band are to be classed as olivine-basalts, although they differ from the more normal types in the scarcity of the pyroxene and iron-ores, and in the fact that by far the greater portion of the felspar (although doubtless originally labradorite) is now in the condition of albite or sometimes of oligoclase.

III. The Upper 'Trap'-Band.

The exposures of the upper band are far more numerous than those of the lower. In the Charfield Green area the southernmost exposure is at a point 150 yards east of Manor Farm, while another occurs in an old nearly filled-up quarry, south of the road at Warner's Court. The upper band is fairly well seen in the railway-cutting north of Charfield Station, and is well exposed in the old quarry (Cullimore's) south-east of Underwood Farm. In the Avening Green and Daniel's Wood area it is well seen at Avening Green, and was exposed in trial-holes south and west of Crockley's Farm. It is also seen at several points in Daniel's Wood. In the Middlemill and Woodford area it is exposed at the Woodford Green cross-roads, at Middlemill Quarry, by the lane leading southwards from Middlemill and west of the Fox Inn. At all these localities the rocks are pyroxene-andesite, and have many characters in common whereby they contrast strongly with the rocks which form the lower band. These characters are as follows[1]:—

(1) The felspars include (*a*) minute needles; (*b*) laths five or six times as long as wide; (*c*) small short crystals, nearly square in longitudinal section; and (*d*) large phenocrysts.

(2) The phenocrysts, which are very much altered, were deeply corroded by the ground-mass, and subsequently bordered by a growth of fresh secondary felspar. Dr. A. Harker suggested, many years ago, that they are xenocrysts, and that the magma in which they are now found is not that in which they originally consolidated. They are invariably present in the rocks of the upper band (see Q. J. G. S. vol. lvii, 1901, pl. xi, fig. 2, also Pl. VII, figs. 1 & 2 of the present paper).

(3) Quartz-xenocrysts deeply corroded by the ground-mass and commonly surrounded by a reaction-border (see Q. J. G. S. vol. lvii, 1901, pl. xi, fig. 3, & Pl. VII, fig. 1 of the present paper) are most characteristic. They have been met with at the following localities:—the old quarry opposite Warner's Court, Cullimore's Quarry (Charfield Green), Avening Green, Daniel's Wood, Woodford cross-roads, and west of the

[1] See description, Q. J. G. S. vol. lvii (1901) p. 281, of a rock from Daniel's Wood; also *ibid.* pl. xi, figs. 2 & 3.

Fox Inn (Woodford). The reaction-border, although now in some cases consisting of chlorite or calcite, was originally of pyroxene (monoclinic or rhombic or both).

(4) The presence of a considerable amount of glassy material, often having a yellow colour, in the ground-mass is very characteristic. In some cases, as in a rock from Avening Green (135), the ground-mass is almost entirely glassy. The rock from the east of Manor Farm (90) is also very glassy. In other cases, as in a rock from opposite Warner's Court (11) and one from Daniel's Wood (31), patches of glass occur, showing the 'intersertal structure' of Rosenbusch in typical fashion.

(5) Patches of ground-mass having a different grain from the remainder, and probably of the nature of xenoliths, are very characteristic of the rocks of the Daniel's Wood and Woodford area. These patches are of three kinds. Some of them consist of felspars longer and of more uniform shape than those occurring in the main part of the ground-mass, and recall the characters of the rocks of the lower band (see Pl. VII, fig. 2). Others are patches with a darker and more glassy ground-mass than that forming the bulk of the rock. Both these kinds of xenolithic patches occur in the rock from Daniel's Wood (31 & 38), while the glassy type is met with also in the rock from opposite Warner's Court (11) and from Heathermead, Woodford (125). In a third type, represented by rocks from Cullimore's Quarry, Charfield Green (42), from Avening Green (135*) (see Pl. VII, fig. 3), from north-west of Daniel's Wood (103), and from the northern end of Daniel's Wood (103*), the xenolithic patches are of a markedly variolitic character. In general appearance the felspars of the upper band vary much in shape, and contrast a good deal with the uniform laths of the lower band.

As was the case in the lower band, while the felspars were presumably all originally near labradorite and some remain so, in the majority of cases the extinction is straight, and the felspar is now albite or oligoclase. In the rocks from the following localities:—Daniel's Wood (31), Middlemill (29), Heathermead, Woodford (125), and Avening Green (135), the felspar is still wholly or partly labradorite. In a rock from Crockley's Farm (105) many of the felspars are chloritized. On the other hand, in a rock from Middlemill (16) the felspars are wholly converted into oligoclase; in one from west of the Fox Inn (110) they are mainly oligoclase, sometimes edged with albite; and in one from Cullimore's Quarry, Charfield Green (3), while the felspar was originally andesine-labradorite, it is now largely converted into oligoclase-albite.

Pyroxene, which is relatively scanty, always occurs in very small crystals, and includes both augite and enstatite. Sometimes the two minerals are present in the same rock (31, 109). The quartz-xenocrysts always have pyroxenic borders. The rock from opposite Warner's Court (11) is an example of those in which the pyroxene is augite; but, in the majority of cases (125, 135), the pyroxene is represented by bastite-pseudomorphs after enstatite. In some cases the pyroxene is replaced by chlorite (3, 9, 104*), in other cases there is no pyroxene (15, 98, 122).

A marked feature, in which the rocks of the upper band differ from those of the lower, is the complete absence of olivine.

The rocks are sometimes highly amygdaloidal, as at Cullimore's Quarry, Charfield. Amygdaloidal rocks also occur in the railway-cutting north of Charfield Station (9), at Middlemill (122), and by the stream south of Middlemill (15). The material filling the vesicles may be calcite; or partly calcite, partly chlorite; or partly chlorite, and partly spherulitic chalcedony, as in a rock from Crockley's Farm (104*).

A very characteristic feature is the scarcity of iron-ores. Some of the rocks are stained with ferric oxide; but magnetite (though occasionally present in small quantities) is never plentiful, and in many of the rocks is completely absent (15, 31, 105, 110).

Mr. E. G. Radley has determined the following silica and alkali percentages of rocks from the upper band:—

	SiO_2.	K_2O.	Na_2O.
E 11. Opposite Warner's Court	56·13	—	—
E 31. Daniel's Wood	53·80	0·68	2·84
E 110. West of Fox Inn, Woodford ...	52·44	2·70	2·33
E 54. Avening Green	55·64	—	—

IV. Key to Localities (as the exposures are followed from south to north).

Numbers of rocks from the lower band, referred to

4, 5, 130. South-east of Charfield Station.
30, 140. Whitehall Villa.
17, 50, 120, 121, 134. Damery Quarry.
18, 129. Mickle Wood.

Numbers of rocks from the upper band, referred to

90. East of Manor Farm.
11. Opposite Warner's Court, Charfield.
9. By railway north of Charfield Station.
3, 42. Cullimore's Quarry, Charfield.
54, 135, 135*, 136. Avening Green.
104*, 105. Trial-hole south-east of Crockley's Farm, Tortworth.
31, 38, 103, 103*. Daniel's Wood area.
98. Woodford Farmyard.
16, 29, 122. Middlemill Quarry.
15. By stream south of Middlemill.
125. Heathermead, Woodford.
109, 110. West of the Fox Inn, Woodford.

Note.—An isolated patch of trap (103) exposed in the lane north-west of Daniel's Wood cannot be worked in with either band, and would seem to be a separate intrusion. If that be the case, it would be expected to present the characters of the lower band. It is, however, clearly of upper band type. The exposure is obscure, and it is perhaps just possible that it may be part of a

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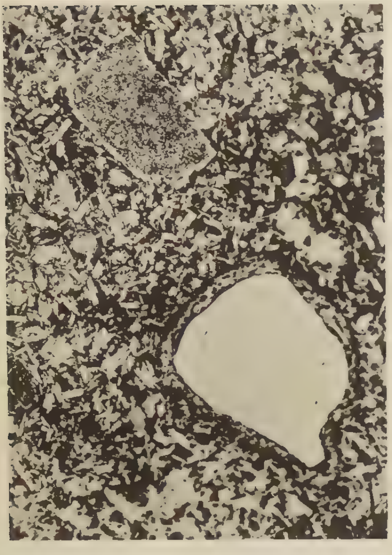


2

3

S.H.R. & J.E.L. photomicro.

IGNEOUS ROCKS of the TORTWORTH INLIER.

H.H.B. photomicro.

JUNCTION of BASALT and INCLUDED BLOCK of SANDSTONE, DAMERY QUARRY

large mass not *in situ*; but I have examined the exposure on several occasions with that possibility in view, and in each case have concluded that the rock must be considered to be in place.

V. Summary and Conclusions.

The igneous rocks associated with the Silurian rocks of the Tortworth Inlier form two bands, the lower of which is probably intrusive; while the upper, which is associated with calcareous tuff, is contemporaneous. The rocks of the two bands, though showing well-marked differences, have several features in common. In each case the felspars, although doubtless originally labradorite, are now wholly or partly in the condition of albite or sometimes oligoclase. In each case pyroxene is present only in the form of very small grains, is relatively scanty, and predominantly enstatite. Iron-ores are scarce, and other accessory minerals are almost unrepresented. Amygdaloidal rocks occur in each band. The rocks of the lower band are characterized by the presence of pseudomorphs after olivine, and by the relative abundance of iron-ore. They may be grouped as olivine-enstatite-basalts.

The rocks of the upper band are especially characterized by the corroded quartzes with pyroxenic borders, and by the greatly altered and corroded felspars bordered by fresh secondary material. Both quartz and felspar are clearly xenocrysts. Peculiar xenolithic patches of the ground-mass are also very characteristic. Olivine is absent, and iron-ores are either very scanty, or completely absent. The rocks may be grouped as pyroxene-andesites.

Dr. Herbert H. Thomas has most kindly examined some of my slides. I am, in particular, deeply indebted to him for notes on the felspars.

The cost of the analyses, and part cost of cutting sections and of the illustrations, has been defrayed by grants from the University of Bristol Colston Society.

EXPLANATION OF PLATES VII & VIII.

Plate VII.

[All the figures are magnified about 15 diameters.]

Fig. 1. E 110. Pyroxene-andesite, west of Fox Inn, Woodford (upper band). The section shows a quartz-xenocryst with a pyroxenic border, also a weathered felspar-xenocryst with a border of fresh secondary felspar. (See p. 108.)

2. E 31. Pyroxene-andesite, Daniel's Wood, Tortworth (upper band). The section shows a deeply corroded felspar-xenocryst, and a xenolithic patch differing in grain from the bulk of the rock. (See pp. 108, 109.)

3. E 135*. Pyroxene-andesite, Avening Green (Upper Band). Part of a variolitic xenolith. (See p. 109.)

Plate VIII.

Junction of basalt and included block of sandstone, Damery Quarry, showing cracks and fine threads of igneous material radiating from the basalt into the margin of the sandstone. × about 15 diameters. (See p. 108.)

Discussion.

Mr. L. Hawkes recalled, in order to explain the presence of the corroded quartzes in the pyroxene-andesite, the suggestion made many years ago by Dr. Alfred Harker, with regard to such occurrences in general, that the individuals had sunk into a basic magma from an overlying acid one. Considerations of density rendered the sinking of quartz in many basic magmas unthinkable, and indeed, so far as the speaker was aware, no demonstration was yet forthcoming that any such settling had taken place in acid magmas. The dolerite of a composite dyke in Iceland recently examined by the speaker contained corroded xenocrysts of quartz and acid felspar, which could be matched with the larger crystals of the associated quartz-porphyry. He suggested that the basic magma had caught up portions of the acid one in which the large quartz and felspar had already grown, and that, before the consolidation of the dolerite, the acid liquor had been assimilated and the crystals attacked. The irregular distribution of the xenocrysts was in accord with this idea. He asked the Author whether the features of the Tortworth rock would render such an explanation possible.

The Author referred the previous speaker to two papers by Dr. Harker in the Geological Magazine for 1892. The very wide and uniform distribution of these xenocrysts in the rocks of the upper igneous band seemed impossible of explanation on the view that the quartzes were mechanically caught up by the magma.

[March 17th, 1924.]

7. *The* River-Gravels *of the* Oxford District.

By Kenneth Stuart Sandford, B.A., D.Ph., F.G.S.

(Read June 20th, 1923.)

The object of this paper is to investigate the contents and mutual relations of the Pleistocene fluviatile deposits associated with the headwater streams of the Thames, and to find what bearing they have on the history of the river and of Quaternary times.

The paper is rather of the nature of a first report, and contains much introductory matter, for the district to be considered has not received the amount of attention which has been paid to other parts of the same river.

The subject will be dealt with as follows:—

I. Introductory Section.

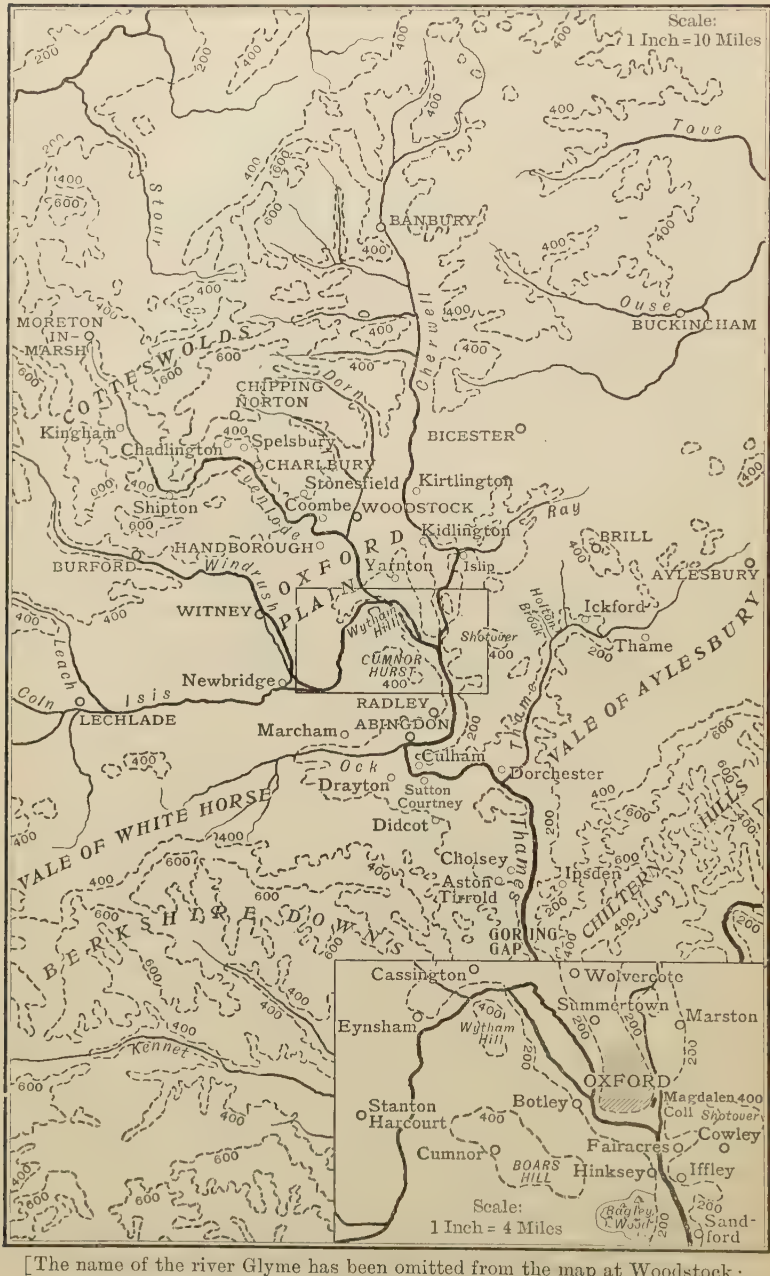
(1) Area of Work.

The district in which the work has been carried out may be defined under two headings:—

(i) Area of detailed work and close observations.

(ii) A wider area which has come under observation, but which I have not been able to keep under careful scrutiny day by day.

Fig. 1.—*Topographical map of the Oxford district.*



[The name of the river Glyme has been omitted from the map at Woodstock; and the name of the area of Ot Moor has been omitted east of Islip and south of the Ray.]

(i) Roughly, the country lying within the bounds of the Oxford Special Sheet, Geological Survey Map, 1908.

(*a*) The Thames from Newbridge to Culham.
(*b*) The Evenlode from the upper end of its gorge near Chadlington by Charlbury, to its junction with the Thames at Cassington.
(*c*) The Cherwell from Kirtlington to Oxford, where it joins the Thames. Ot Moor (Ray Valley).
(*d*) The Thame as far up its course as Ickford.

(ii) The country enclosed by a line drawn on the map through the following places:—Banbury, Buckingham, Thame, Cholsey, Didcot, Marcham (near Abingdon), Newbridge (about 4 miles south of Stanton Harcourt), Burford, Moreton-in-the-Marsh (at the head of the Evenlode Valley), and then along the Cotswold escarpment back to Banbury.

Topography and Solid Geology.

At the outset it will be well to give a brief description of the terrain, though this is known to any resident or to students of the country of Prestwich (1),[1] Osborne White (2), Davies (3), and other authors who have dealt with the so-called plateau drifts and similar deposits.

The relief of the area is determined by three main and roughly parallel escarpments running from north-east to south-west and their dip-slopes:

(1) The Cotswold escarpment.
(2) The dip-slope of the Oolites, capped by the Oxford Clay.
(3) The Corallian-Portland escarpment, capped by the Lower Cretaceous rocks of Cumnor Hurst, with Wytham Hill, Shotover, and, farther north, Brill, in the Bicester country.
(4) The Vale of White Horse and Vale of Aylesbury behind the above range of hills, dominated on the south and east by
(5) The escarpment of the Chilterns and the Berkshire Downs.

The Thames or Isis and its tributaries, the Windrush, Evenlode, and Cherwell with the Ray, drain the Middle and Lower Jurassic country, and converge on Oxford, where they unite to form the main River Thames (Isis). The Thame drains the Vale of Aylesbury, and joins the Thames at Dorchester a few miles above Goring Gap; while the Ock on the other side drains the Vale of White Horse and the Chalk escarpment, and joins the Thames at Abingdon. For some miles round Oxford the Isis, Evenlode, and Cherwell flow in the plain of Oxford Clay until they unite near the city, and on reaching the Portland-Corallian escarpment (Sandford Gap), the Thames passes from the Oxford Clay without break on to the Kimeridge Clay, and in turn on to the Gault.

[1] Numerals in parentheses refer to the Bibliography, § V, p. 164.

I 2

On the north-east the Ray and Thame drain a peculiar area made up almost entirely of clay:—Oxford Clay, Ampthill Clay (which replaces the Corallian limestone series on the east), and Kimeridge Clay. In the Ray basin the lithological change in the Corallian rocks, together with the greatly broken nature of the rock in the Islip district (due to much faulting),[1] gives rise to the great low-lying plain known as Ot Moor, covered with alluvium which passes by three different gorges to the watercourses of the Cherwell and Thame; a fourth channel is blocked by low-lying river-gravel.

(2) The Grading of the Headwater Tributaries of the Thames.

The Continuity of the Rivers.

As might be expected in an area of fairly soft sedimentary rocks, drained by a river-system which apparently is fairly well matured, there is no discontinuity of any one of the rivers at its point of confluence with another in the Oxford plain: thus the Ray joins the Cherwell without break of the curve of descent of either river, and so it is with the junction of the Glyme stream and the Evenlode (now artificially broken by sluices), of the Holton Brook and the Thame, and of all the main rivers with the Isis. If we ascertain the river-level at various points, the thalweg of each can be plotted; and, in each case (Isis, Evenlode, and Cherwell), a regular curve is obtained, which would doubtless show minor irregularities if more detailed work were carried out. These, however, are explained by structural and topographic conditions, and have no significance in this paper. Rapid falls may be situated at and about confluences, and occur in narrow funnel-shaped parts of the valley where it pierces an escarpment.

Graphs are appended (pp. 118–19) of the three rivers mentioned above; they have been constructed from my own levelling, horizontal distance being measured roughly along the present course of the rivers, not across the larger meanders.

The same continuity cannot be said to exist among the rills and winter bournes which rush down the coombes and minor valleys to join the nearest main stream. It is interesting to note that some of the coombes are at least of Neolithic age, since implements of this period are found in and near them: a measure of the rate of destruction of the country, and of the establishment of regularly graded streams.

The graphs and the most elementary investigation of the ground show clearly enough the close continuity and even grading of the present headwaters of the Thames: it remains to be seen whether the same conditions obtained in earlier times.

[1] Also to an anticlinal axis pitching eastwards into higher ground.

(3) The Presence of River-Terraces, and their Continuity with the Thalweg of the Present Streams.

The late Clement Reid (4) suggested, in his paper on the deposits of the Sussex coast, that there may be no terraces whatever in the Thames Valley, and that the gravels at all heights may be parts of one sheet belonging to a single period—'frozen soil-gravels': it may be well, therefore, not to take the presence of terraces for granted, but to enquire into the matter.

In some regions of the Upper Thames, gravel-slopes somewhat of the nature suggested are to be found: thus, a mantle of implement-bearing gravel sweeps down the Chiltern escarpment in the neighbourhood of Goring Gap (Ipsden and Brightwell); but this, I believe, is a deposit formed by surface-washes, possibly aided by surface-movement on the escarpment-slope, its formation having been perhaps continued over a prolonged period of time, without any direct bearing on what was happening on the banks of Thames and Thame. Such formations have little in common with the gravels bordering the river in the present valleys about Oxford.

In some parts of the Thames it has been found impossible to maintain the terrace classification, because two gravels, each of which separately can be defined as of one terrace or another, unite when traced farther: this is a feature of the lower parts of the river-course where there is little or no fall, nor has there been for a very long time. They belong principally to the estuarine zone of the river, and, although they doubtless cause much confusion, no other condition can be expected in this part of a river, especially when the vertical range between the two terraces is not great at any part of the thalweg.

Thus, down-wash gravels and gravels with small vertical distance between them may form a continuous sheet, and contained implements and fauna may or may not disclose the identity of one deposit masked by another. Neither of these conditions is observed to any appreciable extent in the Oxford district.

Two other features would seem to give the appearance of a continuous sheet of gravel: first, the tail and surface-creep of a bank of gravel masking the slope below it, and passing on to a lower gravel-bed; secondly, later gravels of subsidiary streams flowing down the dip-slopes may occupy the position of a much more ancient deposit, and, descending transversely across it, may continue a bed of deposition far below it, even into the present channel. Such might be looked for at any part of the river's course, but more particularly where the river passes through a gorge down the sides of which rapidly-flowing streams, with high erosive power, hasten to join the main stream.

The position of these streams may alter as time proceeds, and so it seems that a mantle of gravel, truly fluviatile and bedded, may take its place over more ancient deposits, redepositing them in the process, and, to add to the confusion, incorporating in the new deposit the fossils of the old.

Fig. 2.—*Thalweg of the Upper Thames and base-level of the terraces bordering it, so far as mapped.* (*See pp. 116, 120.*)

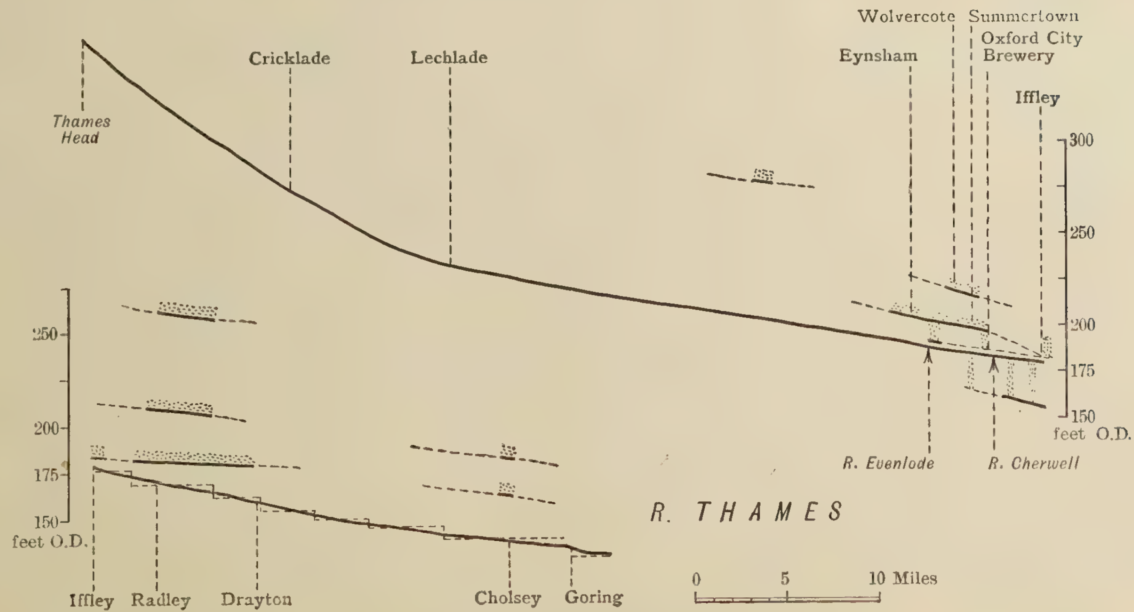
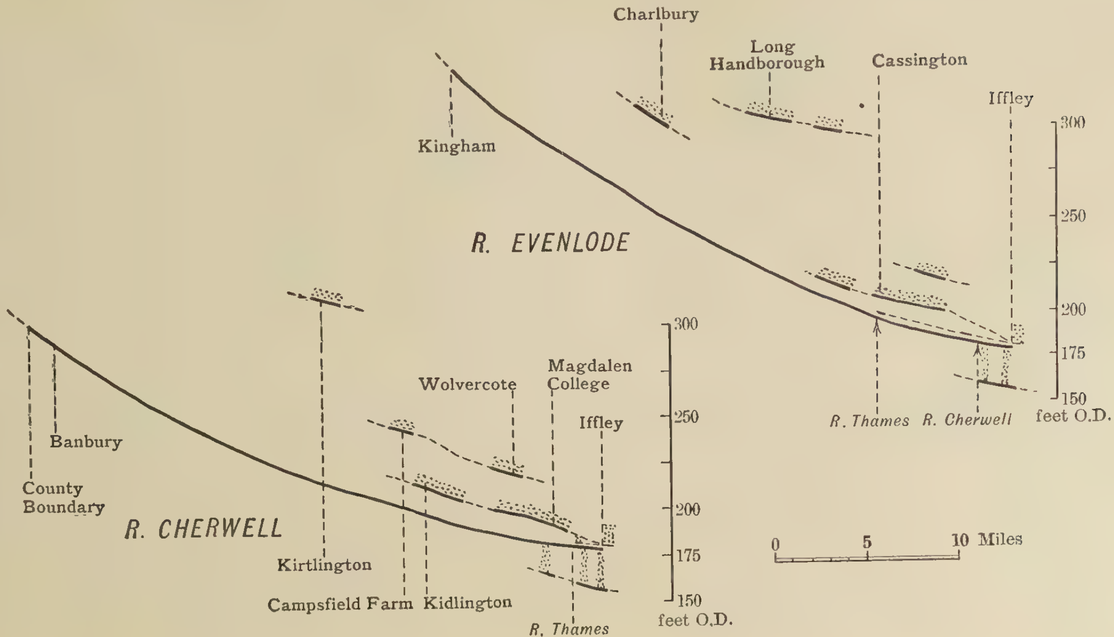


Fig. 3.—*Thalweg of the Evenlode and Cherwell; their confluences with the Thames, to Iffley, so far as mapped.* (See pp. 116, 120.)



I have been unable to work in the Reading area, and have had to rely on published papers; but I believe that a process such as the above may account for some of the perplexing problems that are to be met with there. Such mantles are missing (so far as my observations have shown) in the greater part of the headwater region above the gorge of the Chilterns.

A glance at the geological map tells a different story, and observation in the field confirms it. The deposits around Oxford are disposed in terraces; their number and location will be dealt with shortly, but terrace for terrace they can be traced over the region, always (within a few feet) at the same height above the stream that they border and the waters of which laid them down. This is important, although not altogether unexpected. In a fair open country like that around Oxford one might expect to find terraces: the waters are not cramped in a gorge, nor is there cause for the surface-drainage to find its way across the higher river-terraces in large or swift streams. In fact, the springs rise from the base of the gravels, which act as their reservoirs, and tend rather to accentuate the terrace character than to mask it. The fall of the rivers is rapid, and features tend to be clearly cut: we are in a region of that part of a great river which has remained longest in its juvenile state. This fact is illustrated by the absence of an 'alluvial stage' of any of the terraces (except the Wolvercote site).

It has been stated that the terraces rise with the present river-level; and such is the case. In places are rapid falls of one or the other; but the same relation remains, and it is fortunate that the banks of gravel have been preserved in sufficient length to rule out the possibility of one terrace being correlated with another farther away which, in reality, is part of a higher or a lower deposit.

The only case wherein the terrace system may be said to break down is in the relation of the lower terrace to the buried channel: the latter is but newly identified in the area, and little is yet known of it. There is, however, a continuous thickness of gravel from the bottom of the latter to the top of the former: the two are at present not clearly to be differentiated, and in fact probably belong to the same phase of the river's history. The same holds good, I believe, in the case of the similarly placed gravels in the lower reaches of the river (5).

In the accompanying figures (2 & 3, pp. 118–19) with the thalwegs of each stream the gravels are shown that occur with it, so far as I have mapped and levelled them. This type of figure is at best incomplete and apt to be misleading, since some of the deposits mapped are certainly deposits of the margin of the stream, others of the centre: in this case, there is nothing that need mislead. The figures give an introduction to the deposits that we are about to study, and will call to mind that drawn by Mr. H. Dewey, in his joint paper with Mr. R. A. Smith on Swanscombe (6), with which, however, I do not propose at the moment to try to couple them. With all their faults, and they are

many, such figures show first, the thalweg of the present stream; secondly, that of the ancient deposits, and the latter are seen to correspond with the former.

II. Stratigraphy and Geology of the Terraces, with the Evidence of the Presence of Palæolithic Man, and the Contemporary Fauna.

The Plateau Drift.

It is a matter of essential importance that the relation of the river-terraces to the so-called plateau drift should be determined, before any attempt is made to describe or discuss the terraces themselves.

The Rev. Charles Overy, in a paper read recently before the Geological Society (7), dealt in great detail with the deposits lying at about 140 feet above the present levels of the rivers of the Thames Basin. I do not propose to enter on any discussion of this work: for the present, it suffices to say that Mr. Overy identified at least two glacial stages in the river's history, prior to the deposition of the High Terraces of the Thames. The deposits of these stages appear to be separated vertically by others of fluviatile origin; the latter seem to be rather fragmentary, and I am not convinced that there are two glacial stages: the deposits may be members of the same stage (8).

The first glacial deposits, (P. 350 = 108 m.) of Mr. Overy, are those of the well-known Pickett's Heath and Boar's Hill (9) exposures, the latter possibly an old infilled channel: clearly-striated erratic boulders are known from both these exposures, but it does not lie within the scope of the present paper to discuss fully either the erratics or the formations.

The second glacial horizon lies at or about 140 feet (=40 to 50 m.) above the present river-levels, and comes into immediate relationship with the High Terraces of the Thames around Oxford.

The glacial nature of the drift must first be established.

I will make it quite clear at the outset that I have not seen in this area any unaltered Boulder Clay, except perhaps at Pickett's Heath (10). It does exist on the heights of the Ouse Ray-Thame divide, where the superficial deposits are of considerable thickness.

The deposit that we are considering is only a few feet thick: a very heavy, tenacious, ferruginous clay with boulders and pebbles. It is entirely disordered, doubtless owing in part to the removal by solution of calcareous material.

The evidence of glacial origin lies partly in the nature of the pebbles. All are foreign to the area. Briefly, they may be classified as follows:—

I. Flint. (1) Nodular ochreous flint, with a deep white or brown patina, possibly from East Anglia.

(2) Grey-white nodular flint, which resembles that of Norfolk.

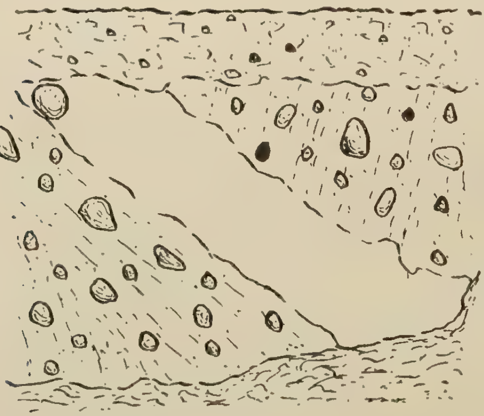
(3) Some nodules of fresh flint from the Chilterns.

II. Quartzites and sandstones, supposedly from the Midlands (11).
III. Tourmaline-grits and schorl-rock.
IV. Rare rocks, some of igneous origin.

A deposit consisting of clay with rocks foreign to the area, or which must have been brought several miles up or across the dip-slope by currents flowing opposite to the present direction of drainage, was certainly laid down by an agent of transport very different from rivers as we now know them. The sole agent that seems at all capable of such a feat is ice—either in slowly moving land-glaciers or floating.

On subangular quartzite-boulders, some measuring $10 \times 7 \times 5$ inches, are groups of finely cut parallel striæ. The hardest rock is

Fig. 4.—*Plateau Drift, showing its general features and the supposed overthrust: the Duke's Brickyard, Coombe, near Woodstock.*



striated, and on more than one face. The striæ are developed on many specimens to a far greater extent than on the block from Wolvercote shown by Prof. W. J. Sollas to the late Sir John Evans, and accepted by the latter as of glacial origin (12).

Attention may be called here to another point which will be mentioned again: namely, that I have found in the High Terrace and the Wolvercote (40-foot) Terrace similar striated boulders, battered, but with the striæ clearly preserved in a worn condition.

I am inclined to think that the above evidence is sufficient to indicate the probability of the glacial origin of the deposits immediately above the High Terrace; but, in illustrating a section, another feature may be noticed (see fig. 4). The section is at Coombe near Woodstock, and shows a disordered deposit with all the features indicated above. A striated boulder and a number of as yet unidentified rocks have been found here: but the feature

that at once strikes an observer is the band of grey-blue clay, about a foot thick, which rises from the base, where it is *in situ*, diagonally across the section. Boulders and pebbles 'set in' on each side of the clay-band. At first this was taken to indicate a land-slide; but the slope of the land to the Evenlode Valley (the pit is on the edge of the river-gorge) is gentle and in precisely the opposite direction, southwards, the clay-band sloping steeply northwards. It seems possible, then, that it is a small over-thrust from the north; but such an explanation is only offered tentatively to account for a feature which (in my opinion) is not explained as an issue of landslip movement.

The so-called glacial beds will now be left for the present, and we may turn our attention to the highest of the terraces of the river: that is, the highest which is in close relationship to the present river, contains remains of animals contemporary with the terrace, and is little altered since the time of its deposition.

Then the relations of Plateau Drift and river-terrace will be investigated.

Terraces of the Thames Basin in the Oxford Area.

A few observations are necessary before we pass to the High Terrace.

Mr. T. I. Pocock (13), in the Geological Survey Memoir of 1908, divided the river-gravels into four terraces, a system which will be maintained in this paper. The highest will be defined as the Fourth Terrace, the lowest as the First (as in Mr. Pocock's account); but a place-name will be given to each terrace, the confusion of numbers being thus avoided. Some comment is necessary at the outset on the number of terraces. Mr. Pocock, as stated, identified four; but, in the last two years, various public undertakings have led to excavations in the river-bed, and I have been enabled thereby to identify a sunk channel or gorge of the Thames in the Oxford district: with the sunk channel I couple the First or 10-foot Terrace of Mr. Pocock, for reasons which will appear later, leaving three terraces above the reach of the present river-waters.

It will be unnecessary to give a detailed account of the distribution of the gravels of each terrace, in view of the completeness of the information on this score supplied in Mr. Pocock's memoir.

The following are the deposits to be considered. The title by which each will be designated throughout this paper is given first.

Handborough Terrace, variously called Fourth, 100-foot, and High Terrace.

Peartree Hill Gravel, previously classified as Plateau Drift.

Wolvercote Terrace, } not always clearly differentiated previously; called Third, 40-foot, Middle Terrace; the former sometimes Northern Drift, and the latter the lacustrine beds.
Wolvercote Channel, }

Summertown—Radley Terrace, called Second or 20-foot Terrace;
Subdivided into
Lower, Older, Gravels, } not previously differentiated.
Upper, Newer, Gravels, }
Flood-Plain Gravels, First or 10-Foot Terrace.
Sunk Channel, not defined previously.

This does not include deposits which will be encountered in the course of the work—such as the warp sands and the various beds of the Wolvercote Channel—nor does the order in which the deposits are enumerated necessarily imply their relative ages.

The Handborough Terrace.

The highest terrace of the Thames Basin in this area maintains fairly evenly a height of 80 to 100 feet (=24 to 30 m.) above the present summer level of the rivers: it is situated high on the flanks of the main valleys, and indeed fringes the very lips of them, or forms high ground between them and the more recent subsidiary valleys.

The Thames (or Isis) itself within the area here dealt with is almost devoid of gravels of this terrace, except at Radley. This is probably in considerable measure due to the southward shifting of the river-course. The shifting is clearly seen on the Stanton Harcourt reach of the river, where the southern bank is bare but for a small patch of the First Terrace, and the terraces are met with in ascending order as one goes northwards from the northern bank: the stream is continually destroying deposits on its south side. The Windrush and Evenlode have gravels of this stage on both their banks; the Cherwell is very scantily supplied with it, and little or none belonging to it has been traced in such parts of the valleys of the Ray and Thame as have come under my observation.

Special attention will be given only to two areas of the High Terrace gravel: first, to the pits of Long Handborough, near Woodstock, which give the name to the terrace, and secondly to the pits at Kirtlington midway between Woodstock and Bicester.

Long Handborough.—There are many exposures in this neighbourhood: the first to be considered is the Duke's Pit, at the forking of the road from Oxford to Witney and to Stonesfield.

Duke's Pit. Some 15 feet of gravel and sandy clay are exposed, and a fair estimate of the total thickness would give 16 feet. The gravel is essentially calcareous, with rolled quartzites and other rocks found in the Plateau Drifts, and occasional large tabular pieces of Forest Marble and other local limestone. No unusual feature of bedding or arrangement is represented; but the top of the pit is marked by a remarkable series of so-called solution-pipes to a depth of 10 feet or more, filled with brown gravelly clay; decayed roots and other features suggest that at least some of these pipes are formed by the roots of big trees, either by concentration of organic salts, or by rifting of the ground by a tap-root. At no remote date Wychwood Forest extended over the site.

The following mammalian remains have been recovered from the gravel itself, not from the pipes:–

Elephas antiquus cf. *trogontherii*, molar.
Rhinoceros megarhinus (possibly *leptorhinus*), molar.
Cervus (?) elaphus, molar.

Height of the surface of the gravel =323 feet O.D.* Height of the Evenlode at the nearest point =222 feet O.D.* Base-level =308 feet O.D.*[1] Height of the surface of the gravel=101 feet above the river. Height of the base-level=86 feet.

Lay's Pit. The height is very nearly the same as that of the Duke's Pit. The uppermost 3 feet are in places disturbed, probably by movement, the deposits being thrown into small folds. The constituents are the same as in Duke's Pit, but the proportion of derived erratics is markedly higher, especially at the base. Bedding is coarsely marked, and some cases of strong erosion and redeposition are noticeable. Much of the lower part is bleached and loose.

In this pit I found a big quartzite-pebble, much battered, but beautifully striated, the striæ being waterworn. Associated with it have been found at the base:—

Elephas antiquus of archaic type; molar.
E. antiquus; molar.
E. antiquus or *antiquus-trogontherii*; molar.
E. antiquus trogontherii; molar.
E. trogontherii; molar.
E. sp.; portion of tusk.

From the same gravel:—

Equus cf. *caballus*; teeth (fragments).
Bos cf. *primigenius*; tooth and limb-bones.

A single drift implement of Chellean type, with heavy ochreous patina, is reported from Long Handborough; but it is extremely unfortunate that it is not known whether the specimen came from these gravels, or from low-lying gravels in the valley nearly 100 feet below (it is now too late for this to be ascertained). Careful and prolonged search has revealed no implement in the higher deposit; the lower is not exposed.

In the Duke's Pit I found near the bottom, but in place, a piece of burnt flint: the flint, on each side of its numerous interstitial cracks, bears a thick white patina. There is, however, no proof that this indicates the presence of Man, and it is quite unjustifiable to suggest that it does, in the absence of any other sure evidence of human work.

Kirtlington.—A road leaving the village, and passing some cement-works, is flanked by gravel-pits just outside the village and near the edge of the plateau in which the Cherwell has cut its bed.

[1] Throughout this paper levels which I have taken or verified by measurement are marked with an asterisk. The work has been done with an Abney level mounted on a stand; but, even so, the error of this instrument is greater than that to be expected from a Dumpy or Theodolite.

In a pit on the north side of the road a thickness of about 12 feet of gravel is exposed; but another on the south shows 20 feet, and the bottom of the pit is within a foot or so of the solid rock.

Both pits exhibit the same features:—bedded gravel, consisting of sand and small pebbles, mixed with great quantities of almost unworn tabular limestone and Liassic ironstone, and measuring as much as $24 \times 12 \times 3$ inches. The large size of the flags of Liassic ironstone is noteworthy.

In both exposures solution has taken place, and in that south of the road, rectangular pits of iron-sand result. The exposure on the north is nearer the crest, and probably a certain amount of re-sorting and movement has taken place. In both cases the lines of bedding are carried through the dissolved parts, but are 'sagged.'

Fig. 5.—*Solution-pits exposed at Kirtlington.*

Two other features are of interest:—

(1) The scarcity of erratic rocks. Only a few small pebbles of tourmaline-rock have been found. Quartzite is as scarce; but fresh, ochreous, and grey flint is fairly common. It is clear that the deposit was formed by the rapid erosion of an area of Liassic and Oolite (the gravel rests upon the latter) scantily covered with Plateau Drift composed chiefly of flint.

(2) The presence of charcoal-like material deposited in patches and long continuous lines of bedding. The presence of hearths

would account for this; but, so far, no implements have been found, and in their absence one must incline to a more natural cause—such as bush fires.

The underlying Forest Marble contains lignite, some of which I tested by the use of diffusion-columns, in order to ascertain whether the material was derived from this source. Such did not appear to be the case, and the substance is probably true charcoal.

Levels in the pit on the north side of the road:—

Height of surface above O.D. = 330 feet.* Height of the Cherwell at the nearest point = 218 feet O.D.* Level of the bottom of the pit above O.D. = 318 feet.

Relations of the Handborough Terrace.—Before we pass on, the relative position of the high terrace must be fixed. In the Evenlode Valley the terrace is cut off sharply by the river-gorge, a deep winding defile formed by a series of incised meanders (14). There is a similar defile in the Cherwell Valley at Kirtlington.

On the side of the Evenlode Valley from Chadlington to Charlbury deposits lie 50 feet above the river: these will be described shortly, and it will then become clear that they do not belong to the Handborough stage, but to the Wolvercote Terrace. The Wolvercote Terrace at Wolvercote itself lies in the middle of the valley between Cherwell and Isis, and might represent the deposit of the centre of the channel on the edge of which was Kirtlington; but the Evenlode Valley would seem to rule out that possibility. The Handborough Terrace is, then, older than the Wolvercote Terrace and subsequent deposits.

It remains to fix an upper limit. Evidence has already been brought forward to show that the Oxford Plateau Drift is probably of glacial origin, not to prove that it is a boulder-clay. But possibly it is not; it is, in my opinion, of glacial origin, and older than the highest terrace of the Thames. The evidence may be summarized as follows:—

(i) The Plateau Drift is in isolated patches; the terrace, where preserved, is in benches of some length.

(ii) The Plateau Drift is decalcified; the terrace-gravel still retains its calcareous matter.

(iii) The terrace-gravel contains a warm fauna, in association with derived glacially-striated boulders.

(iv) The terrace contains large numbers of erratics, the places of origin of which lie more than 100 miles from the river-course, and in other drainage-basins which could at no time have been invaded by the Upper Thames system or drained by it. These erratics are found in the Plateau Drift at levels higher than the terrace.

(v) Although the Plateau Drift has not been seen resting under the gravels of the Handborough stage, nor the latter cutting into the former, surveying and levelling show that the terrace-gravels lie round the foot of an isolated patch of glacial Plateau Drift of the stage of 140 feet above river-level (the Demesnes, near Long Handborough).

(vi) If the drift were younger than the terrace, and of glacial origin, the latter would show some signs of considerable pressure or disturbance: this is not so.

(vii) Edward Hull (15) showed Plateau Drifts sweeping down into the valley near Ascot in the Moreton Vale, covered by low-level gravel. There is no reason why the Moreton Vale and other valleys should not have been partly excavated at this early date; but I know of no other reliable exposure that suggests this, except in Bagley Wood, near Oxford, where the Plateau Drift descends to within 100 feet of the river on the valley-slope.

The foregoing briefly summarized points show considerable weight of evidence that: (1) a glacial deposit exists in the Oxford district; and that (2) it was deposited at an earlier date than the high terrace.

The Wolvercote Terrace.

In the area of the Oxford Special Sheet (Geological Survey Map) of 1908 very little gravel of this terrace is to be found. In the Cherwell Valley there is a patch at Campsfield Farm, near Woodstock, which is not exposed, and so far it has not been possible to dig test-holes. There is the Wolvercote plateau at the former confluence of Thames (Isis) and Cherwell. There is a patch at Radley which has been exposed in the churchyard, where it is about a foot thick.

In the Thame Basin two patches are marked: one is a mere skim of pebbles; the other is at Little Haseley, where there is a section.

Outside the area of the above-mentioned map I have mapped a broad bank running from Chadlington nearly into Charlbury, a distance of about 3 miles, which shows numerous sections. This has not been long enough under observation to provide much material, and so far has yielded remains of *Equus* only.

The following localities will be considered:—

Chadlington—Leafield Road.—A pit on the east side, about half a mile from the village. Here is an exposure of about 8 feet of evenly-bedded gravel: the base is not seen, but its level has been ascertained. A feature of the pit is a later channel, filled with fine gravel capped by heavy ochreous clay: in the channel gravel I found a quartzite-pebble bearing particularly deep striæ, waterworn. A pit on the same terrace at Spelsbury, near by, showed 5 feet of gravel capped by the same thickness of very fine false-bedded red sand.

Level of Chadlington Pit, top	= 338½ feet.*
Do. do. base	= 330½ feet.
Level of the River Evenlode at the nearest point	= 280 feet.*
Level of the base of the gravel above the river	= 50 feet.
Level of the summit of the same	= 58 feet (=19 m.).

The gravel is not continued up the slope of the valley beyond its present height. The ridge between the Evenlode and Chipping Norton is known to be dotted with Plateau Drift; but the slope above the 50-foot bank is bare of gravel. The bench just described seems to be a true river-margin deposit. Below it much of the

land is under pasture; but it has been ascertained that there is a real step between the gravels and the deposits of the present valley-floor.

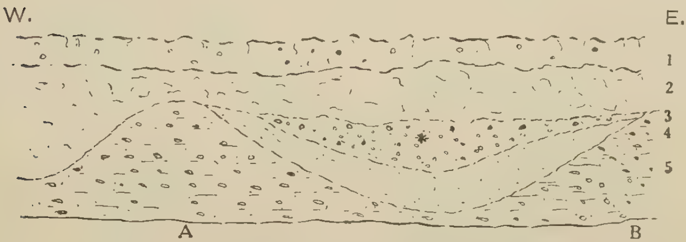
Haseley.—In the Thame basin the Haseley Pit shows all the characters of a deposit derived from the eastern part of the area—close-set sharp iron-sand with abundant flint, including some of the black pebbles common in the Eocene capping of the Chilterns.

The section shows:—

	Feet	*inches*
Soil	1	6
Rubbly ferruginous loam	1	0
Fine gravel	1	0
Sandy clay, passing into gravel at the bottom	1	6

No bones or implements are known from this site.

Fig. 6.—*Section of the Wolvercote (50-foot) Terrace at Chadlington, with a later channel, the whole capped by a down-wash of stiff red clay. (Pit half a mile south of the village, base not seen.)*



1 = Soil, with pebbles. 2 = Stiff clay. 3 = Fine gravel. 4 = Iron sand. 5 = Bedded gravel. * Situation of worn striated boulders.

[Length of A to B = 14 yards; vertical scale: 1 inch = 8 feet.]

Wolvercote.—The terrace is best seen on the Wolvercote plateau near Oxford.

It was designated by A. M. Bell (16) Northern Drift; but it is a river-deposit, and is not to be confused with plateau or glacial drift. It has proved barren of bones and implements, except at margins of the Wolvercote channel; but recently a single thin flake, about 6 inches long and an inch broad, with crust on part of one side, was discovered in digging a foundation (Davenant Road). No particulars, however, are available. The flake can be classified as a knife, and may well be of Acheulean age. The sections here given were seen in the cemetery, which is close to the Wolvercote channel, and in foundations and other diggings of houses erected on a new estate about a quarter of a mile to the south (Davenant Road).

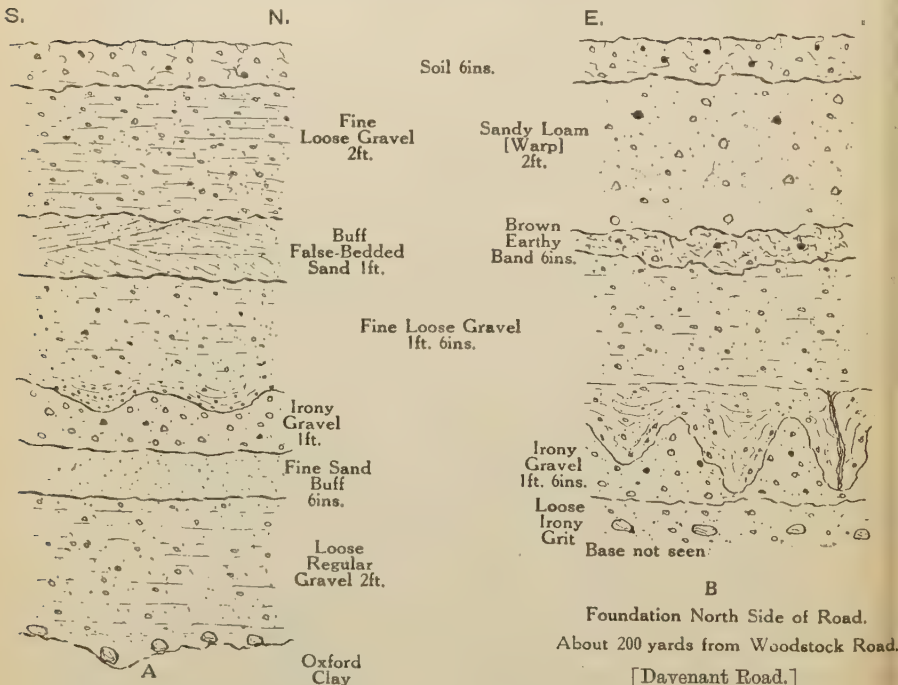
All show the same features:—

(1) An irony gravel, the junction of which with the Oxford Clay is not clearly seen, owing to its waterlogged condition, but seems rather uneven and studded with numerous quartzite-pebbles and boulders.

(2 & 3) A zone of disturbed material. The top of the underlying gravel is in regular folds, sometimes fairly sharp, and conformably above them comes fine calcareous gravel, continuing above the zone as an ordinary bedded deposit.

It is difficult to give a reason for the disturbance: solution may account for part of the displacement, scouring out and redeposition for the rest; there is no evidence for assuming a change of climate. One section showed an earthy band above the upper bedded sand suggestive of a land-surface; but the other sections showed fine-bedded sand or bedded gravel reaching to the uppermost zone.

Fig. 7.—*Section of the Wolvercote (50-foot) Terrace at Wolvercote, showing features of stratification and (in the right-hand section) warp sand.*



Drain Cutting in Road opposite B.
[Davenant Road.]

Foundation North Side of Road.
About 200 yards from Woodstock Road.
[Davenant Road.]

[Levels of top similar; sections about 15 yards apart; level of surface at the site of the pit figured above=227 feet 10 inches O.D.*; level of the Thames at the nearest point=185 feet O.D.*]

(4) The warp sands. Mention must now be made of these, although they will be dealt with again shortly. It is sufficient to say that in some exposures the top gravels and sands are succeeded, but not greatly disturbed by, sands of a totally different nature—entirely disordered, coarse, and earthy, with quartzites and flint-pebbles scattered through them: they are patchy, and fill hollows in the underlying deposits.

It is essential to fix the relation between the Wolvercote plateau and the Summertown Terrace. At the southern end of the plateau a section was recently cut (Roman Catholic Chapel, Woodstock Road) showing about 5 feet of ferruginous gravel which reached to the edge of the plateau. The warp sand was not seen here. A step lies below it, and then follows the surface of the Summertown beds at a level about 12 feet below the top of the Wolvercote Terrace. This seems to demonstrate clearly that the latter is the older. The Wolvercote plateau is now an island between Isis and Cherwell, with gravel of the Summertown Terrace dotted around its flanks.

The terrace will have to be dealt with again, in connexion with the channel.

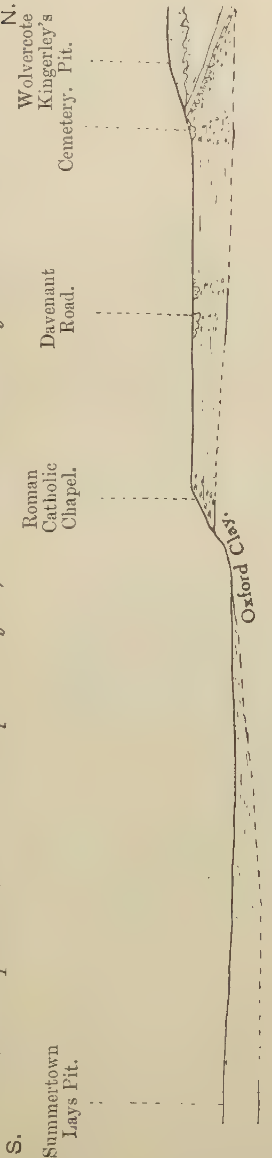


Fig. 8.—*Section showing the Wolvercote Terrace, the Wolvercote Channel cut in it, warp sand resting on both in patches: there is a step at the foot, and then the succeeding Summertown Terrace.*

[From A to B is a distance of $1\frac{3}{4}$ miles; vertical scale: 1 cm. = 20 feet.]

The only other deposit known to me that I believe to belong to this stage, is a bed of about 16 feet of sand and gravel, disturbed and altered at the top, which lies near Cholsey in the mouth of Goring Gap on the 200-foot contour (at the junction of the Papist's Way with the Main Road): the Thames at the nearest point flows at 160 feet O.D. This was shown to me by the Rev. Charles Overy.

Peartree Hill.—An isolated patch of gravel situated about 50 feet above the river-level a quarter of a mile north of the Wolvercote plateau, and marked on the map as plateau-gravel: such a determination would imply that the valley was excavated to this level before the deposition of the Handborough Terrace: although

this is not impossible, in the absence of any definite evidence to support such a theory it is well to look farther. Nearly the whole of the patch was removed many years ago, to reach the underlying Oxford Clay for brickmaking. The pit, long disused and flooded, is still accessible, and I dug a number of sections, only to find that the whole of the remaining material has been disturbed, or at any rate is unreliable. In the course of this work a striated quartzite-boulder was found, much waterworn; but we have already seen at Handborough and at Chadlington that such a discovery has no great significance.

We must rely on previous records of Peartree Hill. A. M. Bell reported a wolf's tooth from the pit (16), somewhat doubtfully perhaps; also he saw a section showing a confused irony gravel driven into the Oxford Clay in tongue-shaped masses. The latter are difficult to explain; the confusion may have been brought about by the conditions obtaining when the warp sands were formed.

Lastly, a flake and a broken point were found here; the point was well worked, slightly worn, and ochreous. These are probably of Chellean age; similar specimens occur in the gravel at Wolvercote.

If, then, we classify the deposit as Plateau Drift, we imply the presence in that deposit of vertebrate remains and implements; instead, we may regard Peartree Hill merely as a detached portion of the Wolvercote Terrace.

Wolvercote Channel.—Previous accounts of the deposits at Wolvercote are to be found in the published writings of Prof. W. J. Sollas (17) and of the late A. M. Bell (18); but it must be remembered that the face of the pit changes year by year as digging proceeds: the account here given refers primarily to the face exposed during the years 1921–1923, although I have known the exposure since early in 1919.

The following are the deposits concerned, in order of deposition:—

(1) Gravels of the Wolvercote Terrace, ravined, but preserved on the flanks of the channel.
(2) Potholes filled with calcareous gravel, occurring chiefly on the flank of the stream, and not clearly seen under the deepest part of the channel where it rests directly upon the Oxford Clay.
(3) Fine irony, calcareous gravel.
(4) A band of hard pan resting on the fine gravel, and capping the potholes.
(5) Fine shelly sand, capped by sandy gravel in one place.
(6) An upper layer of pan.
(Above this lay the peat-bed, now missing, described by A. M. Bell.)
(7) Upper Clays—a great thickness of evenly deposited silt, the bedding of which conforms to the slope of the channel from side to side.
(8) Warp sands driven into the underlying clay.
(9) Surface soil.

The level of the base of the Channel is 223 feet O.D.*; of the ground-surface 241½ feet O.D.*; of the Thames at its nearest point 186 feet O.D.*

Each deposit will be taken in turn, and reference should be made

to the section shown in fig. 9. In order to settle finally the details of the stratigraphy of this well-known exposure, and to provide a basis for exact work I prepared a section, building it up by minor sections taken at intervals of 2 yards or sometimes of 1 yard, on a vertical and horizontal scale of 3 feet to 1 inch.

Fig. 9.—*Section showing the relations of the various beds of the Wolvercote Channel and the older Terrace-gravel (on the extreme right): also warp sands.*

[Scales: horizontal, 1 cm. = 4·5 yards; vertical, 1 cm. = 9 feet.]

0 = Oxford Clay. 1 = Terrace-gravel. 2 = Base gravel and swirl-holes (implements, bones).
3 = False-bedded sandy gravel. 4 = Lower iron pan. 5 = Shelly sands.
6 = Fine gravel. 7 = Upper pan. 8 = Silt. 9 = Warp sand.

The whole was then divided into 1-inch squares, and every fresh discovery was plotted at once in its correct square and noted.

The exposure has altered very little during the period, but fortunately has recently been extended to the west, which allowed of the section being completed. In this way a useful basis has been established: the section is nearly 5 feet long, representing about 70 yards; but, as it has been found (see below) that the present section is not at right angles to the direction of the channel, an exaggerated idea of width is obtained.

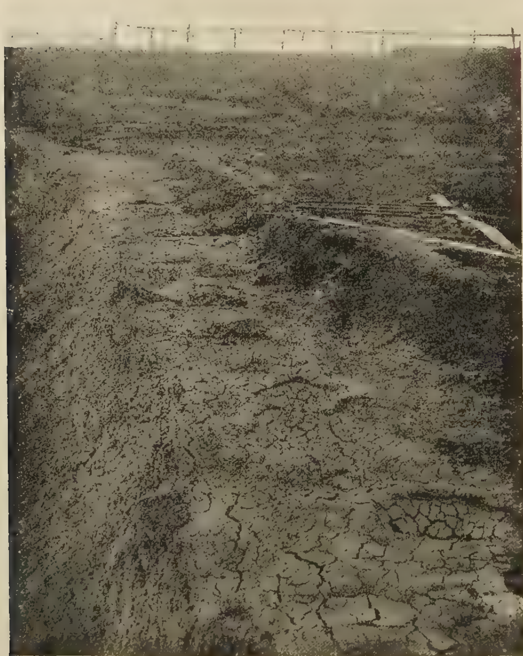
(1) Gravels of the Wolvercote Terrace.—These form the banks of the channel: they were laid bare, much disturbed at the top, on the west side, in the spring of 1923, for the first time in many years; they are not seen to the full extent on the eastern side.

Bones have not been recovered from the gravel where it is with certainty lying *in situ* undisturbed by the channel or by the warp; but it may have furnished some of the vertebrate remains found in the channel. Implements are rare, and one in A. M. Bell's collection (now in the Pitt-Rivers Museum) is a waterworn boucher of very rough pointed type with a heavy butt, roughly flaked, and of light ochreous patina: it has been examined by the Abbé Breuil, and declared to be of Chellean type.

The base of the gravel at Wolvercote, as at Peartree Hill, is furrowed, a feature which thus seems to be common to the base of the gravels of this stage and not superinduced upon them, unless by subterranean drainage.

(2 & 3) Potholes and calcareous gravel.—The 'potholes' lie under the channel, especially on the eastern bank: I have not seen them on the western side; but, in excavating part of the bottom of the channel, I found a sharply undulating surface of Oxford Clay.

Fig. 10.—*Swirl-holes at the bottom of the Wolvercote Channel basement gravel.*



It is difficult to explain their origin: a horizontal strip of the bank of the stream, which has been cleared of gravel, shows the underlying clay to be pitted with them like heavily shelled battle-ground (fig. 10). Observation leads one to think that the channel is running in general from north-east to south-west; but on the east side of the pit it is turning southwards, and on the present east-and-west face it is turning from south to west, flowing at an angle of about 35° south of west; another small branch seems to be coming in from the north. If this turning be true, it mi ht

have set up swirling eddies on the side of the channel on which the current impinged and back-currents on the slack side; this may account for the swirl-holes (as they may well be called)[1] now on the east side of the present east-and-west section, and on the north side of a disused section at right angles to it and meeting it at its eastern end.

The swirl-holes filled with calcareous gravel, and the few inches of calcareous gravel which cover them, have provided nearly all the specimens known from Wolvercote: bones, teeth, and implements. The calcareous gravel in and above the swirl-holes seems to be of the same period of deposition; it contains numerous big quartzite-pebbles at its base.

Of the vertebrate remains the following are known :—

Elephas antiquus (swirl-hole); molar.
Rhinoceros sp.; part of pelvis.
Cervus elaphus (swirl-holes and gravel); many antlers and bones of very large individuals.
Bos primigenius (swirl-hole and gravel); bones.
Bison priscus (?) (swirl-hole); tooth.
Equus caballus (swirl-hole and gravel); teeth with a simple molar pattern, and bones.

Implements: These are of varied types, and range from much abraded Chellean to unworn specimens of Middle or Upper Acheulean and Micoque cultures. An account of them is given in Appendix II (p. 168).

(3, 4, & 5) Upper and lower pans and shell-band.—The iron-pans do not appear to have been recognized before, but are of importance because they seal the lower deposits. Both begin at about the centre of the channel, and run up the eastern bank; they cannot be traced accurately on the west side.

Starting as iron-staining, they pass to a gravel which, as it approaches the left bank, becomes a hard cemented stone: the two pans then meet and pass on together to cap the swirl-holes and to seal under them the calcareous gravels. Here the lower half of the pan (= lower pan of the centre of the channel?) has gone a stage farther, and we have an ironstone of metasomatically replaced Oolite pebbles. Perhaps so advanced a stage is not frequently seen in river-deposits.

In the lower pan, near the junction, was found a large boucher, little worn, of Lower or Middle Acheulean type.

Former collectors at Wolvercote seem to have made little or no record of their implements in regard to depth or bed, but the late A. M. Bell found that the upper clays were barren, which relegates all the implements to the pans or below them: in going over the collection one can pick out numerous specimens that are heavily iron-stained or encrusted, and it is possible that these came from one or other of the iron pans now exposed. Further work might even show differentiation of implements on these lines; of the

[1] The term applied to them by Mr. C. J. Bayzand, B.A., of the Oxford University Museum.

(Upper Acheulean) slipper-shaped implements, though only thirteen are known to me, six are iron-stained. For the present, no further comment is desirable on this score; but it affords a clue well worth following, as year by year excavation proceeds.

Between the two pans lie shelly sands,[1] and cutting across them a very small rill filled with heavy clay containing land shells and black specks of decomposed organic matter. The rill may be as late as, but not later than, the upper pan, and the land shells are the same as those found in the sands.

The only mammalian remains that I have found in this bed are of *Cervus elaphus* (small) and horse with molars of complex enamel-folding comparable to the modern species.

Above the upper pan (that is, at the base of the upper clays) lay Bell's 'peat-bed'. The plants and mosses recognized indicate a temperate climate, and agree with the 'interglacial' forms of Mr. Clement Reid; but two mosses (*Thuidium decipiens* de Not and *Hypnum capillifolium*) are now foreign to the region, the former being found in Britain only in damp places in the Scottish Highlands, the latter no nearer than Siberia and Central and Northern Europe.

The remains of beetles were mentioned by Bell, but were not identified. In searching the Museum I discovered a few of these, and submitted them to Prof. E. B. Poulton: they have proved to be of unexpected interest. Prof. Poulton brought them before the Entomological Society, after showing them to Mr. K. G. Blair, of the British Museum (original identifications and deductions as published in Proc. Ent. Soc. Lond. 1923, p. xv, considerably altered on further study). They are classified provisionally as follows (20):—

Phytophaga:	(1)	*Donacia simplex (?)*. Fragment of elytron. [A form which indicates marshy conditions.]		
Carabidæ:	(2)	*Harpalus dimidiatus* Rossi. Fragment of elytron.		
	(3)	*Synuchus nivalis* Pz.	Do.	do.
	(4)	*Patrobus assimilis* Chaud.	Do.	do.
	(5)	? Genus. Unrecognizable fragment of heavily punctured chitin, possibly from prothorax.		
Curculionidæ:	(6)	*Otiorhynchus ligustici* L. Fragment of elytron with highly characteristic pustulose sculpture.		

Mr. Blair states that these forms are not appreciably older than those known from Pleistocene deposits of the Dogger Bank and of the Irish peat-bogs, the fragments where recognized being nearly all referable with a tolerable degree of certainty to still existing species. In turn, the remains can be dated as of late Acheulean, possibly early Mousterian, age.

(7) Upper Clays.—Until recently these have proved entirely barren: I have found one fragment of rolled bone, too small to be identified, which one is inclined to think has been pointed by hand;

[1] See Appendix III, p. 170.

but, in the absence of other specimens, and in view of the rolled condition of the specimen, it is not desirable to force the suggestion. Much more important was the discovery of a good flake and a trimmed scraper, the former $4\frac{1}{2}$ feet, the latter 9 feet from the surface. The latter is triangular, with a flat base, showing a portion of the bulb and well-developed érailleur; the upper surface still carries crust, but has been flaked on all three edges. Part of the striking platform remains: it has, however, been damaged at a much later date. The implement has been struck from a core; its patina is creamy white, with traces of 'basketwork'; and the whole character of the specimen suggests Mousterian workmanship.

The upper clays are heavy and silt-like, about 14 feet thick in the centre of the channel; at the base they conform to the bedding of the underlying deposits, while at the top they are strongly disturbed by the warp. They fill the channel completely to the brim of the banks, and represent a silting-up stage in a backwater or an overflow deposit of flood seasons. They are not ravined.

The shelly sands, capped in one place by fine gravel, have been strongly ravined; but once the clay started to form, there seems to have been no such strong scouring action: the clay is finely bedded, and banded with alternate oxidized and unoxidized layers, often only a few millimetres thick.

The fauna and flora seem to indicate decreasing warmth of climate.

The Warp Sands.—These are coarse, bright brown sands lying unevenly on the upper clays. They are barren of fauna, and implements found in them are almost certainly incorporated from the surface, or are derived specimens: no culture can yet be attributed to them. They have already been described under the Wolvercote Terrace deposits. A glaciated boulder, somewhat waterworn, was found by Prof. W. J. Sollas some years ago; but this, like others below the level of the Handborough Terrace, is probably derived. If a glacier possessed of the power that a striated boulder suggests had laid down the warp, the soft waterlogged underlying clays would assuredly have been swept away, or at least far more strongly disturbed than they are, and many other traces of its passing would have been left in the valley.

That the warp is a deposit indicating a wet, cold climate there is little doubt (21), and I am also of the opinion that it is entirely of land origin, not fluviatile.

Its junction with the clay is contorted, and masses are driven down into the latter: balls of sand are found in the clay which could hardly have been forced in, unless they were cemented into a hard lump, as they would be by ice or snow. The clay is disturbed and forced up between the downward-thrust tongues of the warp. The whole is superficial: the warp sands have a maximum thickness over the channel of about 5 feet, and disturbance occurs to a depth of about 2 feet into the clays below; but the whole

passes only a foot or so lower than the gravel-bank of the channel.

It is difficult to account for a glacier in the Thames Valley at this time. A simple, and perhaps therefore more reliable, solution seems to be that given for rather similar deposits in other areas—a sludgy mass of frozen soil and snow, solid in winter, liquid or even dried up in summer, moving at times over the hard surface.

In the high terrace of the Handborough stage disturbance of the superficial layers, with pebbles standing vertical, has been noticed: perhaps this is due to similar and contemporary agents. In the Summertown-Radley Terrace I have seen no warp sands: 'solution'-festoons are common. The Wolvercote Terrace was seen cut off sharply, but the warp sand was not identified in the section at the Roman Catholic Chapel. It cannot be proved conclusively that the warp sand is limited to capping deposits of the age and level of the Wolvercote Channel, although such would naturally be the inference deduced from its non-appearance on later gravels.

Mr. R. C. Spiller (Appendix IV, p. 176) has carried out some valuable mineral analyses of (1) the Oxford Clay; (2) the silts of the Wolvercote Channel; and (3) the warp sands of the Wolvercote Channel. From these it is clear that:—

(1) The warp has been derived from adjoining gravel and from underlying silts of the channel, and differs from the latter mainly by the removal of most of the clay, leaving a heavy and sharp irony sand.

(2) Neither the warp nor the silt below it can have been derived entirely from the erosion and natural panning of Oxford Clay. The silt represents the scouring of a much more varied area from a petrological point of view: that is, the local rocks and the capping of Plateau Drifts, which have been seen from the pebbles alone to be very complex.

The Summertown-Radley Terrace.

The so-called 'Second' Terrace is by far the most extensive, and wide tracts of flat land bordering the river have been built up by the waters when they stood about 20 feet above their present level.

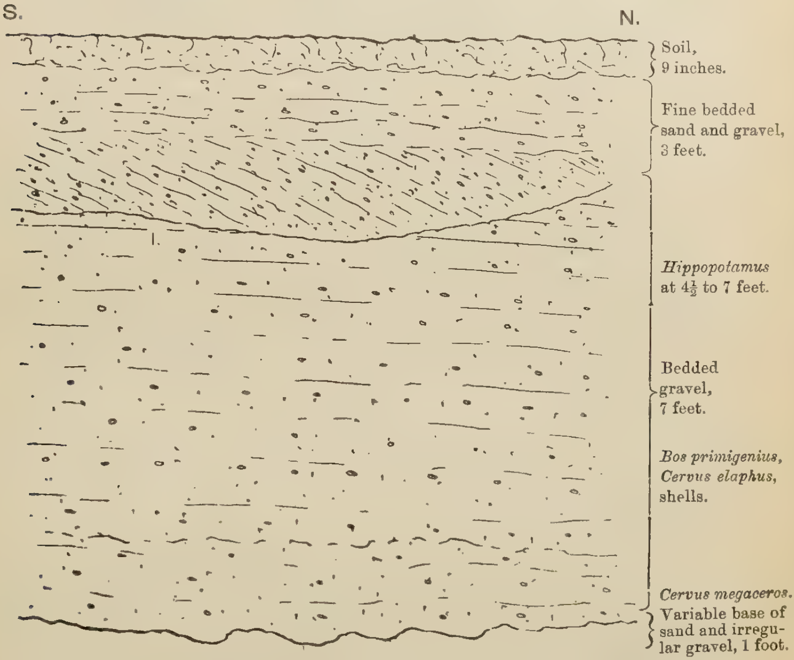
Gravels of this terrace are calcareous throughout, but tend to be coarser and more ferruginous towards the base.

Exposures are numerous, though continual watching is necessary to get useful material from them. A considerable amount of material has, however, come into the University Museum, Oxford, through temporary exposures, and it is fortunate that records of depth have been preserved in many cases. These occasional discoveries will not be dealt with here, but in a tabular analysis of the fauna (see Appendix I, p. 166).

An account will be given here of the more striking exposures which have been under observation for some time. Among previous records, reference may be made to Sir Joseph Prestwich's

paper (22) and to the Geological Survey Memoir of 1908, where will be found such other references as there are to Oxford gravels.

Fig. 11.—*Summertown-Radley (20-foot) Terrace at Eynsham (pit 50 yards south of the railway-station); section showing* Hippopotamus *gravel capped by much later sand and gravel.*



One of the most important observations to be made is that Mammoth teeth, which are extremely abundant in this terrace, are confined apparently to within a foot or so of the base of the gravel, often resting in or upon the Oxford Clay. Teeth, which have been found during the progress of my work, have been so placed, and so has every tooth of which record is preserved. The same applies to remains of *Rhinoceros tichorhinus*: they accompany the Mammoth; but of Reindeer I have found no trace anywhere in the terrace, nor indeed in any terrace in the area, nor are any reindeer remains from a gravel-deposit preserved in the Oxford University Museum. The terrace thus marks the incoming of the 'Northern fauna' without reindeer.

The next point that attracted the closest attention was the discovery of *Corbicula fluminalis* in a few pits, always about midway up the pit-face and above the Mammoth zone. With these two horizons in mind I made an exhaustive study of the available material, and of all incoming specimens found by workmen and by

myself. It was ascertained that the rest of the mollusca and mammalia group themselves about one or other of these zones, so that the existence of the warm climate believed to be required by *Corbicula fluminalis* has been confirmed by the discovery of *Hippopotamus* and other warmth-loving animals in the same zone.

Next, careful observation was made of all sections, in order to ascertain whether two series of gravels are represented in the same terrace, and this was found to be the case. There is an older base-gravel with Mammoth and woolly *Rhinoceros*, and a newer upper gravel which contains the typical warm group of animals and all the mollusca yet found. *Hippopotamus* is reported once only from the base of the gravel with Mammoth and *Rhinoceros tichorhinus*; this is at Iffley, and reference will shortly be made to it. Often the one gravel passes into the other, without any noticeable break or ravinement; sometimes the lower gravel seems to have been re-sorted by the waters which deposited the newer, and so the junction was lost (see Webb's Pit, Summertown). In some cases, apparently, the newer gravel only is represented: either the whole of the older has been scoured out, or the newer has overlapped the ground occupied by the older, and has been laid down directly on the Oxford Clay beyond it (probably the case at the now disused and obscured Wytham pits, in which *Elephas antiquus*, *Hippopotamus*, and *Rhinoceros leptorhinus* have been found).

Thus it is not impossible that Mammoth-remains may in due course be found higher in the gravel than at present observed, and *Corbicula* and *Hippopotamns* lower.

There are seemingly no means now of gauging the original depth of the older gravels; but, although ravining has taken place, there is no evidence of a long break between the dates of the two deposits, and the conditions of deposition are the same for both: that of a fast-running stream; no alluvial stage of either gravel is preserved, for there are no brick-earths or sluggish-water deposits.

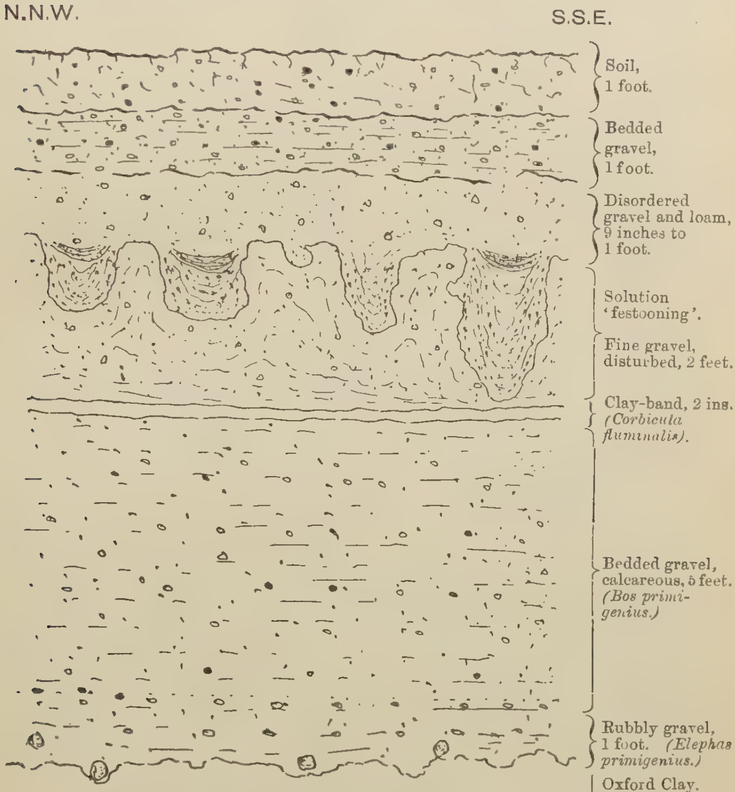
The average depth of the Summertown-Radley gravel may be taken as 10 feet, but thicknesses of 15 feet are known.

It should be noted that the gravels of the terrace are trenched by later and recent stream-beds, as might be expected, and some very fine gravel (false-bedded) seen in a pit near the river at Eynsham Station points to a considerable deposit. No animal remains have been identified from this gravel; but probably it is of much later date than the rest, in which the remains of *Hippopotamus* are unusually prolific, and in which a ramus of *Cervus megaceros*—a unique specimen—was found.

Eynsham.—At the top are about 3 feet of fine pebbly sand and gravel, false bedded, from which no bones have yet been identified, but which is probably of much later date than the underlying gravels: these are noteworthy for the very common occurrence of remains of *Hippopotamus*, and they have yielded a ramus of the jaw of *Cervus megaceros*, a rather unexpected fossil and unique in the district.

Below the *Hippopotamus* gravel doubtless lies the Mammoth gravel: but so far no recognizable bones have been recovered. It should be said that the section, with its mammalia and mollusca (see Appendices), is typical of the Summertown-Radley Terrace.[1]

Fig. 12.—*Summertown-Radley (20-foot) Terrace, at Webb's Pit (south-eastern corner), Summertown; typical section showing Mammoth gravel at the base, and gravel with* Corbicula fluminalis *resting upon it: no well-marked junction.*



[Undisturbed gravel is seen above the solution-'festoons'.]

Summertown.—The section is in a very large clay-pit known as Webb's Pit, Summertown, where 10 feet of gravel are exposed: the base is seen to be even and unpitted, and to contain numerous large quartzite-pebbles.

[1] Since this was written many more remains of *Hippopotamus* have been discovered in the 'warm' gravel; in the basement gravel one tooth of Mammoth and fragments of another have been found resting on the Oxford Clay, and three more are reported from a similar position. This makes the pit one of the most important in the district.

At 9 feet Mammoth teeth have been found: a complete milk-molar (or first true molar) and fragments of two others; a tooth of horse is reported from the same level, as also remains of *Bos*. At about $4\frac{1}{2}$ feet I have found valves of *Corbicula fluminalis*: these were probably odd specimens washed from the more sandy beds seen by Prestwich (22) at St. Edward's School near by, where they were prolific and in the position of growth.

Bos cf. *primigenius* is also known from this level: *Corbicula* occurs in another pit near by, at the same level (near the Pavilion of the St. Edward's School playing fields).

No marked division between the two gravels is shown, the upper part (down to the *Corbicula* horizon) is 'festooned' by solution-formations; but about a foot of gravel remains above, still lying horizontal—an interesting feature. In one corner the gravels above the *Corbicula* horizon give place to false-bedded sands.

One implement is known from Webb's Pit, but was not seen *in situ*: it is a pointed boucher, slightly worn, of Chellean type.

The following implements are also known from the spread of gravel from Summertown to Oxford,[1] and have been seen by Prof. Breuil in the University Museum collection (Oxford):—

(1) Chellean boucher, deeply ochreous, worn.
(2) Upper Chellean boucher, yellow-ochre, worn.
(Both from the Girls' High School.)
(3) Upper Chellean or Lower Acheulean boucher, black and shiny, little worn, from the foundation of the Examination Schools.
(4) Late Upper Chellean boucher, brown and white, with 'basketwork' patina, somewhat worn, from near Marston Ferry [Hawkins's implement] (24).
(5) Late Chellean boucher, brown and iron-stained, worn, found in the University Park.

Magdalen College Grove.—This is probably the most instructive section as yet opened. It lies low, the base being only about 12 feet above the Cherwell at its nearest point.

At the base is a gravel which is laden with bones, tusk, and teeth of mammoth (including several true molars, some much worn, several milk-teeth, and the lower jaw of a very young individual): it is a charnel-house of elephant-remains. On one side (east) it rises to a height of about 4 feet, on the other only about 18 inches remain: it is, in fact, strongly ravined. On the west, north, and south sides of the pit, resting upon the elephant-bed, lies a cemented shell-band about 12 inches thick, from which large specimens of *Corbicula fluminalis* with valves united, in the position of growth, are abundant. Numerous other genera and species are represented, including a large bivalve, which has proved most difficult to extract, despite the application of preservatives in the pit.

[1] Manning Notes:—Lonsdale Road, Summertown: at 7 feet a skull of Cave Lion was found; 3 feet below it, a long, pointed plano-convex palæolith, slightly patinated and worn.

Fig. 13.—*Summertown-Radley Terrace, at Magdalen College Grove, typical section.* *(Pit about 25 yards east of the site of the Gallows.)*

[The gravel is crowded with remains of Mammoth, ravined, and overlain by a shell-bed yielding abundantly *Corbicula fluminalis*: the whole is capped by surface-wash.]

Immediately below the shell-bed (according to workmen) a ramus of Bear, in perfect preservation, was extracted. This important specimen was described and figured by Mr. R. T. Gunther as a new species, *Ursus anglicus* (25).

Teeth and bones of Mammoth project from the lower gravel into the newer, and are found with the top part embedded in the *Corbicula* Band, the lower in the iron gravel.

Corbicula fluminalis and other shells are scattered in the overlying gravel almost to the top of the section, which is covered with deep soil, and in one place interrupted by a much later wash.

Bones occur in the upper gravel; but, so far, no remains other than those of *Bos primigenius* have been recognized.

The importance of the section need not be emphasized: so far no implements have been found in it; but, even as it is, it is a type section of the area.

Radley: (Silvester's Pit). Here the lower gravel, which is heavy and ferruginous, is rarely seen, owing to the height of the water-level. In dry seasons it has been worked, and then excellent specimens

of Mammoth teeth have been found, of which some are preserved in the Radley College Museum. In the upper gravel a mass of heavy iron- and lime-cemented gravel, rounded, about 18 inches in diameter, has been seen, and is believed to be a piece of the old gravel torn from its bed and redeposited as a boulder in the newer deposits.

The junction of new and old gravels is scarcely noticeable.

The pit-bottom is filled with rubble to a little above winter water-level: this is advantageous, in that only a part of the deposit is worked at a time. At the present moment it is that part which I classify as newer gravel: therefore, the warm-climate fauna should be found.[1] Such has been the case, for, as the result of over two years of fairly vigorous working, *Hippopotamus*, *Felis leo spelæa*, and *Corbicula fluminalis* (worn specimen) have been obtained. The Cave Lion, it should be stated, was found some years ago; but its level has been ascertained.

The list of mollusca from the pit is a long one: again all came from the upper gravels; nearly all are in the position of growth (although in a coarse gravel), including *Pisidium amnicum*, which invariably is found with the valves intact. The possibility of mollusca living, and of being preserved, in such a deposit is greater than one might have supposed.

A large pit, about a mile away on the Abingdon Road, which has not yielded a single shell and only one recognizable mammalian remain (tooth of *Equus*), has, on the other hand, produced two implements. These were found by the workmen, and are in the possession of Mr. Dalmaine, of Abingdon. Mr. R. A. Smith has described and figured them (26): they are of Lower Palæolithic type (Acheulean). I regret that it has not proved opportune for me to examine these implements. 'Race' is particularly abundant in this pit.

In gravels belonging to the same terrace, at Drayton by Abingdon, a very large tooth of Mammoth and a tooth of *Equus* were found at the junction of the gravel and the underlying clay: the gravels above have been ravined and re-sorted. I found in this pit, unfortunately not *in situ*, a large boucher, coarsely flaked, a little worn and polished, of Chellean type. The point is chisel-shaped, either by intent or by an accidental blow, before or during its incorporation in the gravel.

Farther down the stream, at Cholsey Cross Roads, two specimens of *Corbicula fluminalis* were recovered from a well-digging. A thickness of 22 feet of gravel was proved here, but it is unknown at what level the shells were reached. Base of gravel at 168 feet O.D. River at the nearest point, 139·6 feet O.D.[2]

[1] The same system is used in the Eynsham pits; when this paper was written I had obtained nothing from the lower gravel (except possibly *Cervus megaceros*). Subsequently *Elephas primigenius* has been found.

[2] These levels were given to me by the Rev. Charles Overy.

Prof. H. L. Hawkins, at a recent meeting of the Geological Society, showed teeth of *Rhinoceros tichorhinus*, which he stated were from a gravel at Aston Tirrold, not more than 20 feet above the present river-level; it is reasonable to suggest that the Aston gravel is of the same stage as the Oxford terrace at a similar level, also yielding *Rhinoceros tichorhinus* (27).

Iffley Road Exposure.

This is the pit designated by A. M. Bell (16) as implementiferous; Mr. R. W. Pocock was inclined to think that it belonged to the first (lower flood-plain) terrace (13); but, by its fauna, it belongs to the Summertown-Radley Terrace, although by its level it comes into the range of both terraces.

The pit was recently reopened.[1] The level was found by an Abney level, and checked by the Rev. Charles Overy and myself with a Dumpy.

	Feet
River-level opposite exposure	179 O.D.*
Top of gravel	193 O.D.*

(2 feet of made gravel were ignored.)

Hence the top of the gravel is 14 feet above the normal river-level.

A thickness of 14 feet of gravel has been proved, which brings the base exactly to present river-level. The bottom of the gravel is usually waterlogged; but it has been dredged, and two very fine sets of teeth of *Rhinoceros tichorhinus*, fresh and unworn, were recovered: nearly all of these still bear traces of Oxford Clay. Mammoth was also found. Some years ago, the bottom of the pit was open to examination, and it is here that the implements lay (28). A large number of very ochreous and much waterworn implements were obtained, as also a number of less worn, slightly ochreous, patinated specimens, apparently of Chellean type. With these were wide flat flakes, some trimmed down one edge, which have been regarded as of the same age. It is to be regretted that, so far, the whereabouts of most of these implements is still unknown to me; but, in the Pitt-Rivers Museum, Mr. H. Balfour has a large boucher with rounded point of heavy grey flint, somewhat ochreous, very slightly worn, which measures $6 \times 3 \times 1\frac{1}{2}$ inches, and is labelled as from a depth of 12 feet: I take it to be a well-developed Chellean specimen. The whole series, if brought to light again, should prove of considerable interest. Some of the implements were embedded in the underlying Oxford Clay. The broad-trimmed flakes of Mr. Manning's account are noteworthy, and their rediscovery might throw interesting light on the exposure.

[1] It is situated between New Iffley Lane and Fairacres Road, between the Fairacres housing estate and the Thames; about 50 yards from the former and 300 yards from the latter.

I have found a large unworn molar of *Hippopotamus* at a depth of $6\frac{1}{2}$ feet, under $4\frac{1}{2}$ feet of undisturbed gravel. A fragment of tusk of *Hippopotamus* from the bottom is also mentioned by Mr. Manning in his Notes, with Horse and Red Deer, and with Mammoth and Woolly *Rhinoceros*. There is no reason to doubt the statements of so keen an observer; but it should be remembered that apparently all the specimens were dredged, not picked out by hand. *Hippopotamus* reached its maximum development in this part of the river during the deposition of the upper part of the terrace.

Here, then, we have the normal Summertown-Radley succession, but at a lower level than usual. At the outset, the following explanation is offered: the deposit lies at a former confluence of the Cherwell with the Isis and near the centre of the channel, not the side. The site is at the entrance of the gorge of the Isis through the Corallian and Portland escarpment, which at the time doubtless lay a little farther north than it does now. The present river falls very rapidly through this gorge between Iffley Lock and Abingdon: thus, the fall at Sandford Lock between these two places is the greatest on the river between Cricklade and Richmond. It seems probable, then, that the river during the epoch of the Summertown-Radley Terrace fell as rapidly between Oxford and Abingdon as it does now. Mr. Pocock called attention to the great fall in the Handborough Terrace between Lower Handborough and Radley, and we shall meet the same phenomenon in dealing with the lower flood-plain gravels and the sub-channel.

The diagram of the terraces given by Dewey & Smith (6) shows the same rapid falls of the High Terrace near Boyne Hill, and of the Taplow and upper flood-plain terrace between Windsor and Staines.

I prefer, then, to classify the Iffley deposit with the Summertown-Radley gravels, on the evidence provided by the fauna and the level.

There is another point: Mr. Pocock, in the Geological Survey Memoir (p. 87), gives the depths of the gravels from Magdalen Bridge (in Oxford) to Iffley; when these are traced, they are found to thicken towards the Thames and Cherwell (that is, southwards and westwards), and they thin northwards and eastwards, so from the site at Iffley the gravel should thin northwards. A recent road alteration about 100 yards north-east of the pit showed 'runs' and pockets of gravel in the Oxford Clay; here was the river-bank, and the pit is situated at or near the centre of the river-bed.

There are two other sites known to me which seem to fall into the same category. One lies at the point of confluence of the Evenlode with the Isis at Cassington (pit behind the Bell Inn), and, as with the Iffley pit, this location may be significant; but the second site is in Oxford itself, and was proved in a boring the record of which Mr. Pocock published in the Geological Survey Memoir.

Cassington.

The surface of the pit stands at 220 feet O.D.; 18 feet of gravel, unbottomed, are known, so that the base is certainly as low as 202 feet O.D. The Isis at its nearest point is at 190 feet O.D., and the Evenlode flows near by at a little below 200 feet O.D.

We have here, then, a deposit reaching to the level of the base of the Summertown-Radley Terrace, and possibly continued below the present-river level. The gravel is calcareous and well stratified; the top is finely false-bedded. No fauna has yet been discovered.

But the base has been proved to rise from the unusual depth of 18 feet or more in a steep slope on the southern side of the deep channel, and to regain its normal depth of 12 feet: the gravel is cut off sharply by the present river flood-plain about 20 yards farther south. On the north of the deep portion the same process is known to take place: that is, the gravel thins out, and again is presented a section across the river-bed of the Summertown-Radley Terrace.

Oxford City Brewery.

(Section from the Geological Survey Memoir.)

Surface-level	209 feet O.D.
Made ground and gravel	$7\frac{1}{2}$ feet
Surface of the true gravel	$201\frac{1}{2}$ feet O.D.
Sand and gravel, and coarse gravel	17 feet
Gravel and clay	$5\frac{1}{2}$ feet
	179 feet O.D.

Level of the river at the nearest point=179 to 180 feet O.D. That is, the deposit descends to the present river-level, and reaches into the zone of the 'Second' Terrace, over 20 feet above river-level (if we ignore made ground and disturbed gravel).

No fauna or implements reported.

So we have:—

Cassington	+20 feet to the approximate river-level.			
Oxford (City Brewery)	+21 feet	Do.	do.	do.
Iffley	+14 feet	Do.	do.	do.

Iffley, from its fauna, particularly the basement fauna (which is strongly represented), I have been inclined to classify as a central channel and confluence-deposit of Summertown-Radley age. The other two exposures are barren; but they too lie in the centre of the channel, and in this connexion it is interesting to note that in the big pit (Webb's) at Summertown, along a face of nearly 100 yards, running directly towards the present river, the bottom is still sinking gently towards the river when it is cut off by the clay-step to the succeeding terrace. Cassington is certainly at a confluence.

Part of the explanation proposed to account for the facts at Iffley (that of rapid fall due to the narrowing of the channel at

the mouth of the Corallian-Portlandian gorge) is, I believe, sound and applicable; but it cannot be applied to the other two cases: they are too distant from the position of the escarpment.

If the deposits belong to the flood-plain and sunk-channel period, the river at some time rose much higher than is supposed, and must have submerged a large part of the Summertown-Radley Terrace: the only evidence of this is to be seen in low-lying parts of the terrace at Eynsham and Drayton, where the top foot or so of gravel does, in patches, show some signs of re-sorting (not to be confused with solution phenomena and known rill-beds).

The Flood-Plain Gravels and the Sunk Channel.

Just as the Summertown-Radley Terrace cuts sharply across the foot of the Wolvercote Terrace, so the First Terrace or Flood-Plain Gravels lie at the foot of the Second Terrace, usually with a narrow clay-belt between the two. The lower terrace is rarely banked directly against the foot of the higher; a break and slight clay-step is so frequently seen that there is no doubt as to the lower being the later gravel, a fact which is borne out by all the circumstances.

As already stated, no records of the submerged channel seem to have been available when Mr. Pocock wrote the Geological Survey Memoir on the district; it has only been by keeping a sharp eye open over the river-valley for a longer period than was available to him that I have been able to obtain some few records.

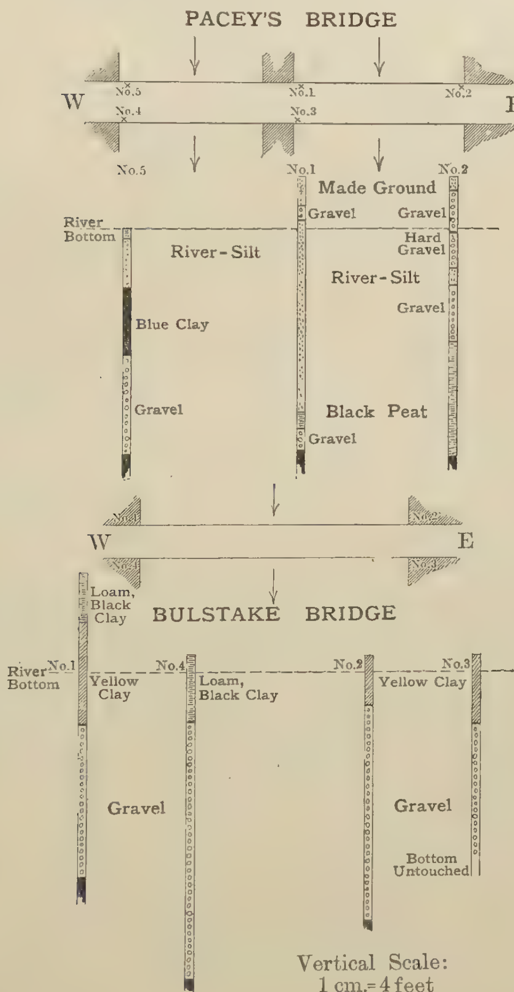
It is impossible to deal completely with either the Flood-Plain Gravels or the Sunk Channel separately: they must be taken together. The Geological Survey Memoir (pp. 83 *et seqq.*) gives several records of thicknesses of the First Terrace gravels; but these are all situated at or near the margin of the deposit, near the former bank of the river. These thicknesses range up to 10 feet. The marginal patches are cut off sharply by the alluvium, or overlapped by it; when sections were opened through the alluvium a few feet of gravel were visible, and then either the Oxford Clay was reached, or the excavation was waterlogged. As usual, the gravels showed every sign of being a true terrace, earlier than the alluvium, and covered by it at the downstream end of the horizontal sheet-like expanses in which the latter is distributed.

Recently, work has been carried out in the centre of the alluvial tracts, and, better still, by starting in 'islands' of First Terrace gravel surrounded by alluvium.

One of the most important of these undertakings was a drainage-trench running along the Oxford-Abingdon Road through New Hinksey, as far as a track turning to the river (about 25 yards from the One Mile Stone), where the trench also turned towards the river. For the greater part of the distance, the trench ran along a First Terrace 'island' and then passed into alluvium. Along the road 17 to 18 feet of fine, loose, calcareous gravel was met with, and the Oxford Clay was usually reached at this depth.

The road is almost flat, and the general surface may be taken as 183 to 185 feet O.D. The river runs parallel to it, about a quarter of a mile away to the east, at 170 feet O.D.: therefore,

Fig. 14.—*Borings in the Sunk Channel, taken across the river-valley, west of Oxford.*



along the road there is a thickness of about 5 feet of gravel above river-level (first terrace) and 13 feet below.

As the cutting turned towards the river, the gravel thickened rapidly: at about this point the alluvium, to a maximum depth of

3 feet, was encountered, and was seen to lie in patches on an eroded surface of the gravel. So soon as the road was left, the gravel was not bottomed at 17 feet, and about 100 yards nearer the river (at a cottage by the river in Long Bridge's backwater) 20 feet of gravel here were passed through unbottomed. At this point, then, there is a sunk channel unbottomed at 15 feet below river-level.

At the Oxford gas-works (standing on alluvium) gravel has been met with, and is still unbottomed at 20 feet.

The construction of a new lock has been begun at Iffley, and here an estimate has been given to me [1] from previous experience, of 25 to 30 feet of gravel below mean water-level (the fall of water at the lock is from 179·72 O.D. to 176·99 feet O.D.).

At the new railway-bridge on the Oxford–Thame line, which crosses the river about a mile below Iffley Lock, caissons have been sunk, and nothing but Oxford Clay encountered. The gravel was struck, but unbottomed at 12 feet, on the Berkshire (south) side of the river. Here, then, the river seems to have cut into its northern bank, and to have deserted its former course.[2]

Most interesting results were obtained in putting down test-holes for a new road-bridge (Pacey's Bridge) near Oxford Castle: records, to which I was allowed full access by the City Engineer and his staff, are reproduced in this paper: they show a maximum depth of 14 feet of gravel below normal water-level. The minute details of the borings are readily seen by a glance at fig. 14, p. 149.

Borings have now been made at another bridge, over a branch of the Thames, about three-quarters of a mile west of this site (Bulstake Bridge) with very similar results (see fig. 14).

Lastly, an interesting section is to be seen at Drayton, near Abingdon:—the second terrace, already mentioned, a clay-step of 6 to 10 feet, with a line of springs thrown out from the base of the gravel; then, at the bottom of the step, a maximum of 1½ feet of First Terrace gravel, only a couple of feet above river-level. Another line of springs follows, thrown out at the junction of the lower gravel with the alluvium which overlaps it, and stretches away to the river. I have worked out fig. 15 (p. 151) to scale, after levelling and measuring the ground.

The above records are quite sufficient to establish two points:—

(1) The presence of a sunk channel, deepening downstream.

(2) The fact that the sunk-channel gravels and the so-called First Terrace are continuous: if the marginal First Terrace gravels were earlier than the sunk channel, then, after this channel was filled, the river must have risen to the level of the First Terrace, to account for the Abingdon Road deposits. This is not impossible;

[1] By the kindness of Mr. E. Burnard, District Superintendent of the Thames Conservancy Board.

[2] So in the Cherwell at the University Park: 20 feet of silt reported below the eastern bank.

but, on the other hand, the whole of the First Terrace may belong to the same epoch and indicate that the river, after scouring out a very deep and probably narrow channel, filled it up again and deposited material to a height of 10 feet above its present level.

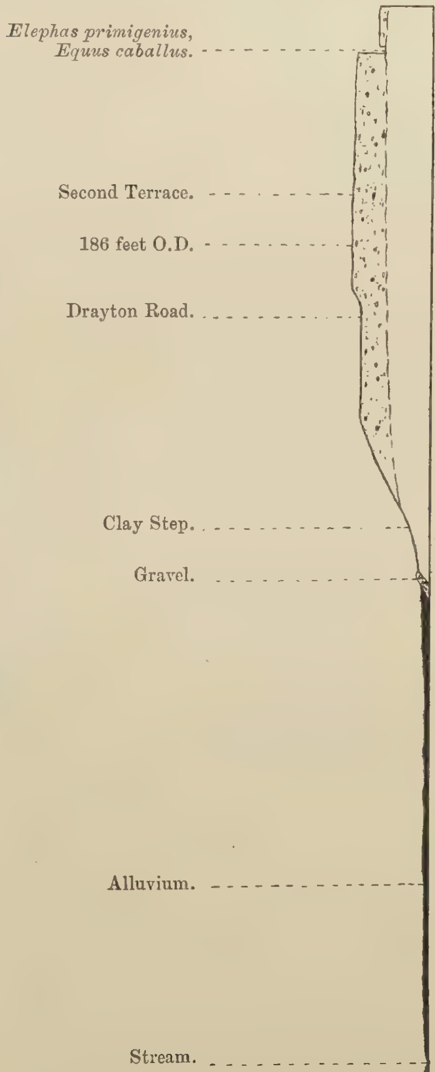


Fig. 15.—*Relations of the Alluvium, the Flood-Plain Gravel, and the Summertown-Radley Terrace: Cox Pit, Gilburn Farm, Drayton.* (*See p. 150.*)

[The Thames at the nearest point is at 152 feet O.D. Vertical scale: 1 cm.=32 feet; horizontal scale; 1 inch=40 yards.]

Possibly, therefore, the oldest gravel after that of the Summertown-Radley Terrace is to be found at the base of the sunk channel (29).

The last phase of the activity of the river is one of erosion approximately to its present level, and the deposition of the alluvium. The alluvium is most clearly described by Mr. Pocock in the Geological Survey Memoir, and it has not been my special study.

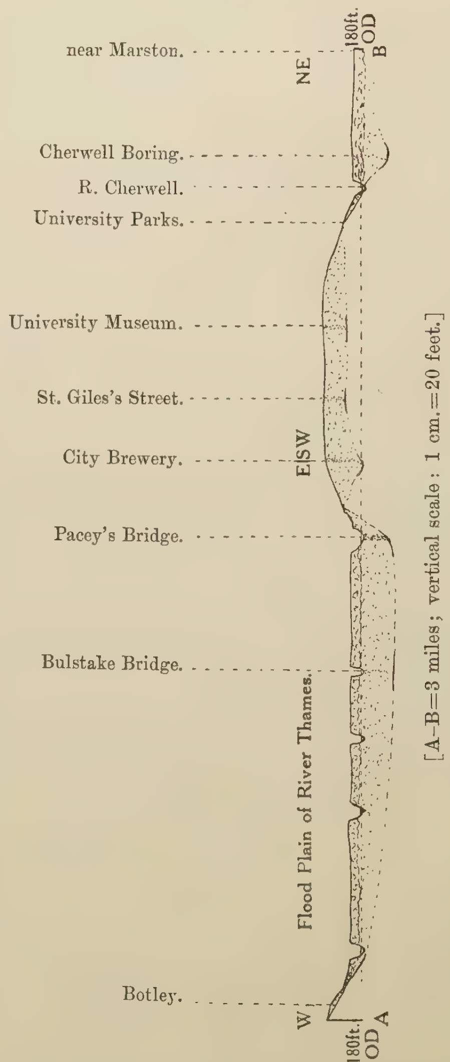


Fig. 16.—*Section across the Thames and Cherwell Valleys (Botley-Oxford-Marston), showing alluvium resting upon Flood-Plain and Sunk-Channel Gravels, the whole at the foot of the Summertown-Radley Terrace.* (*See p. 153.*)

Numerous remains have been found in the river and its backwaters during dredging operations; but the value of specimens so obtained is not great: they include a molar of *Rhinoceros*

tichorhinus from Folly Bridge, very ochreous and much rolled Chellean implements from the North Hinksey backwater and from the river at Cassington. A magnificent molar of *Elephas primigenius*, however, is exhibited in the Oxford University Museum, and bears an old marking in pencil 'bed of Cherwell'; it is little worn, and shows traces of blue clay.

Beneath Christ Church Meadows (alluvium), and at or near the top of the underlying gravel, antlers of *Cervus elaphus* were found, and A. M. Bell reported a skull of *Hippopotamus* from beneath the same meadows (30). I have been unable to find the specimen, but such an object is hardly open to faulty identification. The anomaly which this discovery presents will be discussed further, at a later stage of the present paper.

With the information supplied by the two borings for the Botley Road bridges, as also by the City Brewery boring, and with the body of observations already made, it is possible to draw an instructive section across the Thames Valley at Oxford (fig. 16, p. 152).

III. River History, Climate, and Chronology.

The foregoing discussion and analyses have presented the facts with sufficient clearness, as I believe them to be revealed in the Oxford district: it remains to discover the climatic and other conditions in relation to the chronological order of the deposit.

Plateau Drift.

On direct geological evidence, or by inference from the contents of the High Terrace gravels, and later deposits (that is, derived and waterworn erratics, some of them ice-scratched, found with such animals as *Elephas antiquus*), it seems impossible to escape the conclusion that the oldest deposit with which we have to deal is of glacial origin. I refer to the Plateau Drift, which lies at and about 140 feet above the stream, reaching 160 feet and descending at least to 100 feet. I believe that this deposit was formed under the severest climatic conditions experienced in the area, rivalled only by the higher deposits of Pickett's Heath, which may indeed belong to the same chronological phase.

The significance of this conclusion is obvious, for it places in point of time a glacial stage between the period of the High Terrace and the Pliocene. The exact age of the drifts it is almost impossible to deduce; they may represent a Pliocene period of cold, or they may have been deposited at or after the close of that epoch. It is difficult even to determine whether they are the tumbled remains of a once coarsely-bedded boulder-and-pebble gravel, or whether they were deposited in their present tumultuous condition. The fact remains that, before the deposition of the High Terrace, there was a period of severe climate which must almost certainly have broken the faunal sequence between a part or the whole of

the Pliocene and the succeeding early Pleistocene High Terrace (31). There is no trace in the valleys of any subsequent period of such severe climatic conditions.

Handborough Terrace.

The High Terrace follows, lying about 100 feet above the rivers of the present day, containing a remarkable series of elephants ranging from *Elephas antiquus* of archaic character to *Elephas trogontherii*; also *Rhinoceros megarhinus* (or *leptorhinus*), the first and third being characteristically warmth-loving forms which became extinct, or left the country as the climate became more severe, towards the close of the terrace period of the Thames (32).

I feel fully justified, from the evidence and analogy with other areas, in assuming that the fauna of the Handborough or High Terrace indicates a period of warm climatic conditions. No implements have yet been found; but, from the evidence provided by other parts of the Thames Basin, Chellean and some Acheulean forms might well be expected (33).

The Handborough Terrace lies little below the Plateau Drifts: in fact, there is evidence that it lies within the range of these deposits; but, in the time which followed the completion and desertion of the High Terrace, interesting events took place.

Wolvercote Terrace.

Judging by the Evenlode and Cherwell valleys, the streams had settled into regularly meandering courses, suggesting that (at the close of High Terrace time) the rivers had reached an advanced stage of their development (34). Rejuvenation now set in, and the Evenlode and Cherwell were unable to break from their old channels. Indeed, they have never done so, but have carved for themselves magnificent meandering gorges now nearly 100 feet deep.

The rejuvenation of the streams led to a deepening of the valleys, to the extent of about 50 feet. The climatic conditions during the very long time which this great excavation must have occupied cannot be deduced with certainty. There is no conclusive evidence of another glacial stage.

Unfortunately, in the gravels which mark the halt in the valley excavation no fauna has been discovered; they contain rolled Chellean implements, and there are remarkable features of stratigraphy the significance of which is not fully understood.

Wolvercote Channel.

At the bottom of the Wolvercote Channel we pick up the sequence of events again: here occurs *Elephas antiquus*, though rarely, with large specimens of Red Deer and other animals of wider, or less certain, climatic range. With the bones are found

implements of Middle and Upper Acheulean and Micoque type, some unrolled.

The period which is represented by the infilling of the channel is of especial interest—if we judge by the channel alone, the rivers were reaching a stage of maturity and slow aggradation; but evidence cannot be taken as conclusive on this point, as the channel may have been merely a backwater which was silting up.

Above the gravel already mentioned is an iron 'pan', which was formed at a time of stagnant water, or of non-deposition on the stream-bed.

Shelly sands, clean and false-bedded, follow, and are capped by fine gravel: a rapidly flowing stream must have occupied the channel. The shells indicate neither marked warmth nor cold, *Corbicula fluminalis* is missing, and the whole assemblage can only be described as generally of temperate character. The scanty remains of *Cervus elaphus* which are found here are of small size, and the very few teeth of *Equus* do not exhibit the unusually simple character of the specimens from the basement gravel.

Much of the gravel and sand was swept away, and another pan caps the relics of both; above it was deposited a peat-bed at the bottom of a running stream. The plants and mosses are of species characteristic of a temperate climate, but two of them are known only from cold regions (one from the North-West of Scotland, the other from Siberia). This, indeed, suggests a cold to temperate climate. There followed a period of quiet infilling of the channel with mud and silt to a depth of about 12 feet, which closed the fluviatile stage of Wolvercote. In the silt has been found a small flint-implement, which may well be of Mousterian age.

The deposits of the Wolvercote Channel seems to bear record of aggradation and of a climate which was becoming less warm and equable.

The Wolvercote plateau is capped by warp sands which are generally considered to be a terrestrial deposit formed during a period of very moist and probably frigid climate; the evidence at Wolvercote bears out such an interpretation.

Similar sands have not been revealed on the Summertown-Radley Terrace, although careful search has been made for them; their absence may be accidental; but, when they are so strongly marked on a small plateau, their presence might well have been expected on the much greater area of the Terrace. The natural conclusion is that the sands are older than the lower terrace: and, within the area, nothing so far has been seen to shake this opinion, but I shall refer to the suggestion again later.

If the warp sands which cap the mud and clay of the Wolvercote Channel are correctly considered to be of greater age than the Summertown Terrace, then the climatic change already noted is continued in these terrestrial deposits. The warp might then be considered to have been formed while the river was lowering its bed to find its new base, about 35 feet below the top of the Wolvercote Channel.

Summertown-Radley Terrace.

The base-level being found, aggradation again set in, and a few feet of gravel were laid down. These are often crowded with remains of the Mammoth, and, as already stated, the bottom of the terrace at its junction with the Oxford Clay is studded profusely with teeth of Mammoth of the Siberian type, the thick-plated type also being represented. The Woolly Rhinoceros accompanied the Mammoth; but the Reindeer—the most important of the three which are usually considered to indicate boreal conditions—is missing. It seems probable, however, that the climate was cold when, or just before, the gravels were deposited.

There is strong evidence to show that the 'Mammoth' gravels were almost entirely swept away during a succeeding stage of erosion, which, although it removed much of the gravel already deposited, did not lead to much deepening of the river-bed into the underlying Oxford Clay. Mammoth disappeared as quickly as it arrived: for, in the new gravels, it finds no place so far as known. Its companion *Rhinoceros tichorhinus* disappears also.

The newer gravels bear witness of a climate as warm as that of the High Terrcce. In places are found beds of *Corbicula fluminalis*, with other shells; and with them occurs *Hippopotamus*, which may truly be described as a common fossil in these gravels. *Elephas antiquus* occurs again, with Red Deer and Cave Lion. The last, being a carnivore, was bound to follow its food, or starve; so it may well have been forced to penetrate farther north than its natural habitat, and its value as an indicator of climate is thus reduced.

Worn Acheulean implements are found in the gravels apparently of both stages of the Summertown-Radley Terrace. Again, on the top of the Summertown-Radley Terrace, all trace of an 'alluvial stage' is missing. Coarse clean gravel is found from top to bottom; much 'festooning' disturbs the uppermost few feet.

After aggrading its channel to a maximum of about 15 feet, the river-system has now entered on another phase of rejuvenation (35).

Flood-Plain and Buried Channel.

The difficulty of separating the Flood-Plain Gravel from that of the Sunk Channel has already been discussed: in fact, the discovery of the latter increases rather than lessens the difficulties encountered in the area.

The record of *Hippopotamus* from a shallow depth in the Flood-Plain Gravels suggests that these, in part at least, are the older. Seeing that a skull was found, it is difficult to imagine that it could be a derived specimen: an odd tooth might be, but the bones found in the older terraces are now extremely fragile, and were probably little less so when the Flood-Plain Gravels were

in process of formation. The length of time represented by a deepening of the channels of a river-system must be great, and in this case the vertical erosion amounts to about 10 feet.

There is the following explanation to offer, which may account for the presence of *Hippopotamus* in a deposit generally believed to have been formed long after the extinction of the animal in North-Western Europe.

It has been shown that the centre of the channel of the Thames, and the confluence of the Evenlode and the Cherwell, during the time of the Summertown-Radley Terrace, ran along the line Cassington–Oxford (City Brewery)–Iffley. Along this line the gravels approach very nearly to present river-level, but otherwise are normal to the Terrace. The line passes over the site from which the *Hippopotamus* skull is reported, and here the older gravel would be within reach of the water at the later epoch. It is suggested that by the process of 'incorporation in bulk': that is, large masses of gravel-bank, undercut by the flow of water, slipping gently into the river and being covered up without further disintegration, the skull may have been transferred to the newer gravel unharmed. It would be extremely difficult to distinguish one gravel from another in such a case.[1]

On geological considerations one would be inclined to suggest that, after the completion of the Summertown Terrace, rejuvenation set in and the rivers cut a narrow channel, the bottom of which lies about 15 feet below present water-level and 35 or 40 feet below the top of the old terrace: there followed a period of aggradation, during which the narrow channel was filled with coarse gravel and sand, a bank of gravel was formed varying up to 10 feet above the present surface of the waters, and then by minor oscillations of level the river reached its present position. During this period it deposited the bulk of its alluvium, which is strongly unconformable upon the Flood-Plain Gravels and overlaps them.

Of the climate, fauna, and human culture of this long period unfortunately little can yet be said from work in this area alone; but work by investigators in lower parts of the river may throw light on the matter (36). In this instance our knowledge of climate partly breaks down in the Oxford district, a condition of things that will probably be remedied if the gravels are kept under continuous observation. Indeed, there is good reason to believe that the tooth of Mammoth from the 'bed of Cherwell' is *in situ* there.

The sunk channel in the lower river has been proved to contain an Arctic fauna and flora; but investigators here seem inclined to consider it younger than the Flood-Plain Gravels.

The alluvium in this, as in other districts, contains the fauna indicative of a climate very much the same as that of the present day.

[1] The Rev. Charles Overy states that he has observed this process below Sandford Weir in time of flood.

The sequence of events seems fairly clear. Of the relations of the High Terrace to Plateau Drift and to the terrace of Wolvercote phase (40-foot Terrace) I have no doubt: the same applies to the position of the Summertown-Radley Terrace between the Wolvercote Terrace of the Flood-Plain and Sunk Channel Gravel.

The Wolvercote-Channel group, as it stands, is self-contained; it represents a long period of time, is older than the warp sands, and younger than the Wolvercote-Terrace gravel. The warp appears to be older than the Summertown Terrace, and, if this be so, then the position of the channel is fixed; but, if the warp should prove to be younger than it appears, it seems possible that the channel deposits of Wolvercote are a ravinement of the period of the Summertown-Radley stage.

The evidence briefly is as follows:—The channel is truncated by later erosion (near Wolvercote Church), and Oxford Clay comes to the surface as a steep cliff. The base of the channel is about 38 feet, and the top of the Summertown Terrace about 25 feet, above river-level: then the base of the channel is about 14 feet and the top over 20 feet—or nearly 30 feet—above the top of the Summertown Terrace, as now preserved. It is unlikely, therefore, that the Wolvercote Channel could have been a backwater or cross-channel between the Thames and the Cherwell at as late a period as that of the Summertown Terrace; it is doubtful whether a fast-running river would deposit such a series as we see at Wolvercote from its upper stratum of water, while it was laying down very extensive gravels over 20 feet below this level. On the other hand, the Wolvercote series might have been deposited by a small tributary between the Thames and the Cherwell.

The fauna of the channel seems to correspond to that of a known stage in the Lower Thames, and that of the Summertown-Radley Terrace to another in the same chronological sequence: that is, the channel is older than the Summertown Terrace.

The evidence afforded by the implements is not convincing: those of the Wolvercote Channel carry us to the close of the Acheulean and to the dawn of the Mousterian, and include unrolled specimens. Those of the Summertown Terrace are rolled, and do not seem to represent as advanced a culture as those of the channel, nor probably as late a period. On the other hand, the former are found in coarse gravel, and were of necessity subject to rolling; the latter occur in sands and in fine gravels. In addition, very few specimens are known from the Summertown Terrace, and it is by no means certain that the highest culture that it contains has yet come to light.

The position, then, is this:—on geological grounds there is reason to consider the Wolvercote Channel older than the Summertown Terrace, though it is clearly to be remembered that the channel deposits were not seen in the section at the Roman Catholic Chapel. The absence of *Corbicula fluminalis* in the sands is not to be overlooked, and the presence of *Elephas antiquus* in the underlying gravel, as also in the upper part of the Summertown Terrace, is significant.

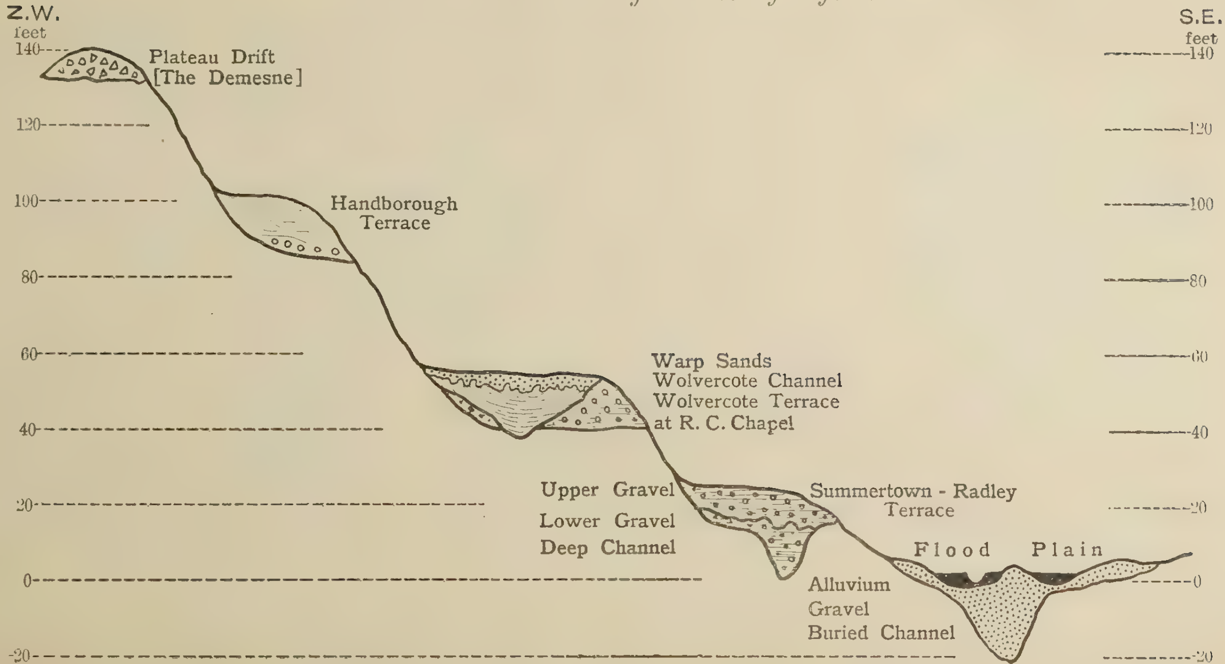
The implements of the channel and of the lower-lying terrace are of much the same age; but, at the moment, younger types, better preserved, are found in the channel at Wolvercote.

On the supposition that an attempt were made to fit the Pleistocene deposits of Oxford into a generally accepted time-scale, harmony might be obtained if the Upper Wolvercote Channel deposits were taken to be younger than the Summertown Terrace. Similarly, one might seek to reverse the apparent relations of the Flood-Plain Gravels and the Buried Channel Gravels to obtain agreement with the results obtained in the Lower Thames. Further research may, indeed, lead to both these conclusions; but, for the present, the matter will be left as it stands.

I now append a table of river history, climate, and chronology, in which the deposits are shown in their present, apparent, order.

	Physical History.	*Climate.*	*Implements and Stage of Man.*
Plateau Drift with striated pebbles.		Cold.	
High (Handborough) Terrace—*Elephas antiquus.*	Erosion, amount doubtful. Deposition, about 18 feet.	Warm.	None: Chellean (?).
Wolvercote Terrace.	Erosion, about 35 feet. Deposition, about 8 feet.	Warm (?).	Rolled Chellean only.
Wolvercote Channel—*E. antiquus.*	Erosion, about 14 feet. Deposition, about 14 feet.	Base warm, sand warm-temperate. Clays temperate to cold. Warp [non-fluviatile], very moist, cold (?).	Unrolled Acheulean and Upper Acheulean. Micoque. Incoming Mousterian.
Temperate-Alpine Plants.			
Summertown-Radley Terrace. *Elephas primigenius.*	Erosion, about 35 feet. Deposition: (?) feet.	Probably cold.	Rolled Chellean and Acheulean only.
Elephas antiquus. Hippopotamus.	Slight erosion. Deposition, about 10 feet.	Warm.	
Sunk Channels and Flood-Plain. *Elephas primigenius (?).*	Erosion, about 40 feet. Deposition, about 25 feet. Erosion, about 10 feet.	Cold, Arctic in part (?).	Upper Palæolithic periods (?). (No evidence found in the area.)
Alluvium.	Deposition very variable, still liable to floods.	As nowadays.	Neolithic and later.

Fig. 17.—*Diagrammatic section of the complete series of superficial deposits of the Upper Thames Basin in the neighbourhood of Oxford.*



Factors of Correlation.

It is not my intention, at the present stage of investigation, to enter on a correlation of the deposits of the Upper Thames with those of the other parts of the river, or of other provinces; but certain features, which have a bearing on the subject, call for attention.

When one views the river as a whole, in the light of impressions gained in the Oxford area, the following points attract one's attention.

(1) Coarse gravels of the Upper River are to be compared, on the evidence of fauna, implements, and level, with brickearths of the lower river: this is, in part at least, a natural function of the thalweg.

(2) All the non-local rocks represented by pebbles in the fluviatile deposits of the Oxford district are found in the local plateau deposits above them, as rounded and subangular pebbles and boulders; these can be traced down the course of the river, and become increasingly comminuted, the hardest and chemically most stable surviving longest.

(3) The Iffley and Cassington sections provide a warning that the deepest parts of ancient river-beds may reach present river-level, whereas the bulk of their gravel rests quite beyond the reach of the river-waters.

(4) Implements may be described as the commonest fossils of the High Terrace of Swanscombe: they are strongly represented in the deposits of the Lower Thames (Swanscombe, Crayford, Ebbsfleet, and other well-known exposures). In this part of the river Chellean (or Strepyan) and Mousterian cultures are preserved in unworn condition, and at known horizons. In the London district implements of those cultures are abundant: very large finds have been made in the Reading neighbourhood, and around Farnham. Through the upper part of the Chiltern Gorge of the Thames implements have not been found so plentifully; this may, or may not, be accidental.

Beyond Goring Gap extreme poverty of human culture is most clearly marked, and here implements have been sought by numerous collectors and archæologists over a prolonged period. The scarcity is thus probably not accidental, so far as search and trained observation are concerned. One is inclined to attribute some significance to the scarcity in the Oxford district, compared with the remarkable abundance in the eastern part of the river. In the Oxford area not a single implement is known definitely from the High Terrace, although the Rev. Charles Overy, in a paper read recently before the Geological Society, commented on a remarkable series of Chellean and pre-Chellean implements from a gravel-filled channel in the Chilterns near Reading, 140 feet above the river. Chellean implements, rolled or unrolled, are as yet unknown from the High Terrace of the Thames in the Oxford district.

In the deposits of the Wolvercote plateau have been found the only notable number of implements; but, after more than 25 years' collecting, barely 70 specimens are known, and these are a mixture of rolled Chellean to Upper Acheulean forms, only the highest forms being entirely unrolled (Upper Acheulean and Micoque). Recently one small specimen, which is polished but not rolled, supposedly of Mousterian workmanship, has been discovered in the upper clays.

From the next terrace not a single unworn implement is yet known, and barely a score of worn Chellean and Acheulean forms; but it should be noted that some of these are indeed very little rolled. They are not, however, in the condition of the highest forms found in perfect preservation at Wolvercote.

Too little is yet known of the Flood-Plain and Sunk Channel; but, so far, no unworn implement has been recovered from them. Poverty so clearly marked is not to be ignored; doubtless further discoveries will be made, but nowadays the condition of things is remarkable (38).

A suggestion, tentative only and founded on negative evidence, is that Lower Palæolithic Man flourished in the Middle and Lower Thames area, but did not penetrate in large numbers or colonize very extensively the basin of the Thames beyond Goring Gap. Why, it is difficult to say: for game and water were both abundant. Much of the land was forest-covered, and beyond lay the heights of the Cotswolds; but the fact remains. Possibly, in Mousterian and late Acheulean times the river-valleys, bedded in blue clays from Goring Gap to far above Oxford, were waterlogged and swampy: the foregoing suggestions gain weight when the mammals are considered.

(5) There are some curious features exhibited by the fauna that are of exceptional interest. The ancient 'warm' fauna lingers long in the area, the 'northern fauna' is not established.

The fauna of Long Handborough (such as there is) agrees with that of Swanscombe.

Summertown-Radley corresponds in level, in mollusca, generally in vertebrata, and possibly in industry, with the Crayford Brick-Earth, but with Mammoth and Woolly Rhinoceros at the base. Above, we find *Elephas antiquus* and *Hippopotamus* (at its zenith) with solid beds of *Corbicula fluminalis* and other shells, including two or three species as yet unknown in other Pleistocene deposits. Of Reindeer, which appears in the Taplow Terrace (of the Geological Survey), and is most characteristic of the Upper Flood-Plain Gravels of the Lower and Lower Middle Thames, not a single specimen has been found in the river-gravels of the Oxford district.

There are other discrepancies, which may be made good; but, if we bear in mind the very long time during which collecting has been going on in the Oxford district, the known assemblage of fauna and the known gaps in it are of some significance. So far as collecting is concerned, there is a specimen (part of a ramus of

Rhinoceros tichorhinus) from Thame which was figured by Douglas, in his 'Antiquity of the Earth' 1785, as 'Fossil animal incognitum': another was found in 1825, and collections have constantly been made, at least from 1870 onwards.

Only one Bear is known, and that a single specimen and of a new species. *Hyæna* and *Ovibos moschatus* are as yet unknown, and other species are known by single specimens only.

Can it be that mammals and Man advanced up the river, that the ancient fauna became established beyond the Chilterns and, segregated there, lingered on and flourished more abundantly than it did in the lower parts of the basin? Did the northern fauna advance likewise up the Thames and reach the Oxford plain for a time only, even then depleted of some of its members? Lastly, did Man follow the same route, and, reaching the Chiltern escarpment, pass beyond it only in small parties? These are questions of surpassing interest to which the answer may, with some degree of truth, though as yet tentatively, be given in the affirmative.

Thus it appears that, in any attempt at correlation of deposits throughout the Thames, neither mineralogical composition nor lithological character, neither fauna nor relative level, can be accepted as indisputable criteria; and even Man himself may fail us by failing to distribute himself equally throughout the river-basin, or to leave behind him as many of his instruments as we would desire.

IV. Summary and Conclusions.

It has been shown that ancient river-terraces occur in the headwater region of the Thames Basin, west of the Chilterns, and that they maintain the same curve as the thalweg of the present rivers with which they are associated.

There is no discontinuity of the terraces of the headwater tributaries of the Thames at their confluences near Oxford.

Three terraces are identified above the present flood-plain, and to each, in order to avoid confusion, a place-name is given :—

Handborough Terrace	about 100 feet above river-level.
Wolvercote Terrace, Wolvercote Channel	about 40 feet above river-level.
Summertown-Radley Terrace	about 20 feet above river-level.

Below the last are flood-plain gravels, and a sunk channel has been identified. There is an absence of alluvial stages and of brickearths (except in the upper part of the Wolvercote Channel).

The Handborough Terrace is in immediate contact with, and younger than, a plateau-drift which I consider to be of glacial origin.

Each of the three terraces contains a warm-climate fauna with *Elephas antiquus*; but there is evidence of colder conditions in the upper part of the Wolvercote Channel, and in the base of the succeeding terrace.

M 2

The Proboscidea are represented by a series of forms, from *Elephas antiquus* of archaic characters to the Siberian Mammoth.

The warm-climate fauna lingers long in the area, and is strongly marked by abundant remains of *Hippopotamus* and *Corbicula fluminalis* in gravels which rest upon deposits containing *Elephas primigenius* and *Rhinoceros tichorhinus*, both gravels being of post- or late Acheulean age (Summertown-Radley Terrace). The full suite of 'Northern forms' is not found in the district.

Palæolithic implements are scarce, and unabraded specimens are confined as yet to the Wolvercote Channel: these are of Acheulean and Micoque cultures. Abraded Chellean implements are found in the Wolvercote Terrace and abraded Acheulean specimens in the Summertown-Radley Terrace.

At this point I may conclude. I desire to emphasize that the paper is intended as a record of fact and as an introduction to an important part of the River Thames, in the hope that it may be of use as the basis of future work.

In conclusion, I must express my sincere gratitude to those who have assisted me during the progress of the work: to Prof. W. J. Sollas and Prof. J. E. Marr for much helpful criticism and advice; to Dr. A. Smith Woodward and the late Dr. C. W. Andrews for the determination of the vertebrata; to Mr. Henry Balfour, through whose kindness I was permitted to study the implements from Wolvercote in the collection of the late A. M. Bell; to Mr. Leeds for permission to study the Manning papers; and to Mr. J. Reid Moir for many fruitful discussions.

To Mr. A. S. Kennard & Mr. B. B. Woodward I am indebted for their analyses of the mollusca, and to Mr. R. C. Spiller for his work on the clays and sands of Wolvercote.

I am also indebted to the Rev. Charles Overy for an original outline of the map produced in this paper.

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Appendix I.—Synopsis of the Pleistocene Vertebrata of the Oxford District.

Handborough, 'High', Fourth or 100-Foot Terrace.

Oxford University Museum and Author's Collections.

Teeth :—

Elephas antiquus (archaic).
E. antiquus.
E. antiquus trogontherii.
E. antiquus or *trogontherii. Cf.* Sœrgel, Palæontographica, vol. lx (1913) pl. ii, no. 4.
E. trogontherii, or cf. *E. primigenius* of Ilford
Bos sp.
Equus sp.
Rhinoceros megarhinus or *leptorhinus.*[1]
Cervus (?) elaphus.

All seen by the late Dr. C. W. Andrews, F.R.S.

Wolvercote, Third or 40-Foot Terrace.

Oxford University Museum and Author's Collections.

Terrace-Gravels—None.
Basement-Gravel of Channel.
E. antiquus, tooth; bones.
Rhinoceros sp., pelvis.
Equus caballus, with simple molar crown pattern, and bones.
Bos primigenius, tooth and bones.
Bison priscus (?), tooth.
Cervus elaphus, bones and antlers.
Channel, lower sands.
Cervus elaphus, antlers (fragments).
Equus caballus, with complex molar crown pattern; teeth.

Upper clays—none found.
Warp sands—none found.

Summertown-Radley (Second or 20-Foot Terrace).

Oxford University Museum and Author's Collections.

Lower Gravels.	Upper Gravels.
Eynsham.	
Elephas primigenius, teeth.	*Hippopotamus major* (abundant). *Bos primigenius*, teeth and bones. *Cervus megaceros*, ramus. *Cervus elaphus*, bones and antlers (fragments).
Wytham (37).[2]	
Elephas antiquus, lower jaw. *Rhinoceros leptorhinus*, tooth. *Hippopotamus major*, fragment of tusk.	*Cervus elaphus.* *Equus caballus.* *Bos taurus (?).*
Yarnton.	
Elephas primigenius: 'at and near the bottom a profusion of teeth and tusks of *Elephas primigenius*' (37). *Rhinoceros tichorhinus*, teeth.	

[1] This specimen is in the possession of Mr. J. Kibble, of Charlbury.

[2] See also J. Phillips, 'Geology of Oxford & the Valley of the Thames' 1871. There is reason to believe that the mention of Mammoth from Wytham (p. 464) refers to *Elephas antiquus.*

Kidlington.

Rhinoceros tichorhinus, teeth (level unknown).

Summertown:—

(*a*) St. Edward's School Foundation (22).

Elephas primigenius, teeth.	*(Corbicula fluminalis.)*

(*b*) Webb's Pit.

Elephas primigenius, teeth. *Equus caballus*, teeth.	*(Corbicula fluminalis.)* *Bos primigenius*, teeth and bones.

Levels unknown (22):—

Rhinoceros tichorhinus.
Equus caballus.
Cervus elaphus.
Cervus capreolus.
Sus scrofa.

(*c*) Lonsdale Road.

Felis leo spelæa, skull (at 7 feet; notes of the late P. Manning).

Oxford.

(*a*) University Museum (Foundations of the Dyson Perrin Laboratory).

Bison priscus, face and horn-cores. *Elephas primigenius*, teeth.	

(*b*) Observatory.

Rhinoceros tichorhinus, tooth (specimen dated 1825).

(*c*) Magdalen College Grove.

Elephas primigenius, abundant remains. *Ursus anglicus* (25), ramus.	*(Corbicula fluminalis.)* *Bos primigenius (?).*

(*d*) Holywell Street (Drainage-work done about the year 1869).

Elephas primigenius, abundant remains.	

(*e*) Records of *Elephas primigenius* also at the Old Angel Inn, Little Clarendon Street, Iffley Drainage (about 1868), and other sites at which isolated teeth were found.

Iffley.

Elephas primigenius, teeth. *Rhinoceros tichorhinus* (common), teeth. *Equus caballus.* *Cervus elaphus.* *(Hippopotamus major ?)* fragment of tusk, missing. (Notes of P. Manning.)	*Hippopotamus major*, tooth.

Radley (Silvester's Pit).

Elephas primigenius,[1] teeth.	(One specimen, worn). *Corbicula fluminalis*. *Hippopotamus major*,[1] tusks. *Cervus elaphus*, bones. *Bos primigenius*,[1] bones and teeth. *Felis leo spelæa*,[1] skull, complete. *Equus caballus*, bones and teeth.

Abingdon. Levels unknown.

Elephas primigenius, teeth. *Rhinoceros tichorhinus*, teeth. *Hippopotamus major*, teeth.	Radley College Museum.
Equus caballus, teeth.	
Ursus ? (canine tooth). *Bos primigenius*, bones and teeth.	Abingdon Museum.

Drayton, by Abingdon.

Elephas primigenius. *Equus caballus*, with complex molar crown pattern.	

In the foregoing synopsis, in cases in which the specimen has not been found by me, or within the period during which I have been studying the gravels, very definite evidence has accompanied each specimen before it has been classified as belonging to Lower or Upper Gravels. If this evidence has been incomplete, or open to doubt, there has been no hesitation in classifying the specimen under the title 'level unknown'.

Appendix II.—Implements of the Basement-Gravels of the Wolvercote Channel.

In order to avoid breaking the continuity of the text, the description of the largest number of implements from any one bed of the Oxford deposits is relegated to this brief appendix; but, although the determination of culture is achieved, the collection as a whole would well repay much closer examination than is possible at the moment. It is greatly to be hoped that one day it will be possible to gather together all the implements known from the basement-gravels of the Wolvercote Channel, and carry out a thorough examination: if this be done, probably alterations will be made in the account here given; but, in broad outline, it should remain the same.

In the circumstances, no figures will be given; but, when all the implements can be compared side by side, and more detailed work is attempted, this should certainly be done. The great plano-convex implements are some of the most beautiful objects of Lower Palæolithic art, and the simplicity of the Micoque forms is

[1] Specimens in Radley College Museum.

striking. Some of the small plano-convex implements may very well belong to the Micoque industry.

The reader is, therefore, asked to bear in mind that this is the preliminary detailed classification and determination, and that it is carried out under limiting conditions. Numerous types are represented.

(1) A few very battered flakes, with deep ochreous patina.

(2) Worn, acutely pointed bouchers, with heavy butt: yellow, blue, and white, with blue and yellow patinations. In four collections:—Pitt-Rivers Museum (the late Mr. A. M. Bell's collection), Ashmolean Museum, University Museum, and my own collection, as many as twelve of the type are preserved; two specimens in the University Museum were identified as of Chellean age by Prof. Breuil.

(3) Pointed bouchers of fine technique, simple but masterly flaking with little retouch: mostly unpatinated, little worn, yellow and black or grey. I have seen fourteen specimens of this type; about half of them are iron-stained or iron-encrusted. Three specimens in the University Museum collection were classified as Chellean-Acheulean by Prof. Breuil. A single implement in my collection is somewhat of this type with a very reduced butt, pointed, though with the point missing; the flaking is strong, long rippling flakes having been removed and little retouching done. This Prof. Breuil identified as Lower or Middle Acheulean, and another, in the University Museum, as Acheulean.

(4) The remaining implements represent the highest cultures present in the basement-sand and gravel. They are of different workmanship from the foregoing, and belong to a slipper-shaped or plano-convex type (19).

They may be divided into:—

True plano-convex type.

(*a*) Small plano-convex bouchers.

(*b*) Magnificent implements measuring up to 10 inches in length.

Bouchers of Micoque type.

(*a*) Highly arched, with a flat base and a trimmed butt. The colour varies with the flint, but generally is grey or black; that is, fresh flint. They are mostly unpatinated, and are barely rubbed or polished. They may be considered to be a series so little abraded that they are almost certainly contemporaneous with the sand and gravel in which they lie. The flat base has usually been retrimmed, and the edges of the implements have been retouched. Some at least have been struck from a core; yet, despite this fact, neither these nor those described below (*b*) are normal Levallois flakes, but are comparable to the late Acheulean forms which approach in

some respects the Levallois type. They are probably of Upper Acheulean or Acheulean III industry.

One specimen was seen by Prof. Breuil, and classified as Upper Acheulean.

(*b*) These probably represent the highest stage of evolution of the type described above: they are about 10 inches long and nearly 4 inches broad, thin at the rounded point, thickening slightly towards the butt. They were detached apparently, though not certainly in every case, from a larger block; but both faces are etched with beautiful fish-scale flakes, and this with their size, shape, and finish, precludes them from being classified as Levallois flakes. They are unpatinated, and in perfect preservation. Only four are known.

A single implement was classified by Prof. Breuil as Micoque, and I have seen another that corresponds closely to it. The first specimen is sharply triangular in section, increasing rapidly in thickness towards the butt, which is of little trimmed crust: flaking is very simple, and the implement has been made with a minimum of work for a maximum of effect. It is unpatinated, ironstained, and slightly smoothed over the arêtes by sand-rubbing.

A grattoir in my collection from the same gravels is comparable with Mousterian forms, but is assigned by Prof. Breuil to the Middle Acheulean.

Appendix III.—The Pleistocene Non-Marine Mollusca. By Alfred Santer Kennard, A.L.S., F.G.S., and Bernard Barham Woodward, F.L.S., F.G.S.

[Plate IX.]

The Non-Marine Mollusca of the Pleistocene deposits near Oxford have received but scant attention in the past, and we are greatly indebted to Dr. K. S. Sandford for submitting to us the series found by him during his recent survey of the district. Although the list of species is not extensive, two species are new to science; and it is evident that further work will add greatly to the number. We hope that this pioneer work is only the prelude to an exhaustive study of these deposits and their fauna.

Eynsham.

Dr. K. S. Sandford obtained two species from this deposit: namely, *Unio prestwichi* sp. nov. and *Sphærium radleyense* sp. nov.

Kidlington.

Four species are recorded by John Phillips from Pleistocene

gravel at Kidlington,[1] and two species are preserved in the Oxford University Museum. The list will thus be

Fruticicola (Capillifera) hispida (Linné).
P *Cecilioides acicula* (Müller).
P *Ancylastrum fluviatile* (Müller).
P *Planorbis planorbis* (Linné).
Corbicula fluminalis (Müller).

P=On the authority of Phillips.

Marston.

In the collection of the Oxford University Museum are examples of *Corbicula fluminalis* (Müller) from this locality, but the exact site is unknown.

Magdalen College Grove.

From a temporary excavation in Magdalen Park Dr. Sandford obtained fifteen species, namely:—

Jacosta (Cernuella) virgata (Da Costa) 1 example.
Fruticicola (Capillifera) hispida (Linné) 1 example.
Cochlicopa lubrica (Müller) 1 example.
Limnæa pereger (Müller) 2 examples.
Limnæa truncatula (Müller) 1 example.
Bithynia tentaculata (Linné) 7 examples.
Valvata piscinalis (Müller) common.
Unio littoralis, Lamarck, 2 examples.
Unio prestwichi, sp. nov., 2 examples.
Corbicula fluminalis (Müller) common.
Sphærium rivicola (Leach) 1 valve.
Sphærium corneum (Linné) 1 valve.
Sphærium radleyense, sp. nov., 3 valves.
Pisidium amnicum (Müller) 6 valves.
Pisidium henslowanum (Sheppard) 2 valves.

Radley (Silvester's Pit).

The series obtained by Dr. Sandford from this section has been supplemented by examples collected by Mr. R. Winckworth and Mr. A. Wrigley; we are thus able to place on record twenty species, namely:—

Jacosta (Cernuella) virgata (Da Costa) 3 examples.
Jacosta (Xerophila) itala (Linné) common.
Fruticicola (Capillifera) hispida (Linné) 6 examples.
Succinea pfeifferi, Rossmässler, 4 examples.
Ancylastrum fluviatile (Müller) 6 examples.
Limnæa pereger (Müller) common.
Limnæa palustris (Müller) common.
Limnæa truncatula (Müller) 4 examples.
Planorbis leucostoma, Millet, 6 examples.
Valvata piscinalis (Müller) common.
Valvata macrostoma, Steenbuch, 1 example.
Unio prestwichi, sp. nov., common.
Anodonta anatina (Linné) 1 fragment.
Corbicula fluminalis (Müller) 1 fragment.
Sphærium corneum (Linné) common.

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[1] 'Geology of Oxford & the Valley of the Thames' 1871, p. 467.

Sphærium radleyense, sp. nov., common.
Pisidium amnicum (Müller) common.
Pisidium henslowanum (Sheppard) 1 valve.
Pisidium subtruncatum, Malm, 2 valves.
Pisidium cinereum, Alder, 7 valves.

Summertown: St. Edward's School Site.

Sir Joseph Prestwich, in 1882, recorded twelve species of mollusca which he had obtained from the excavations for the foundations of new buildings at St. Edward's School, Summertown.[1] A series from this section is preserved in the Oxford University Museum, and the revised list is as follows:—

Fruticicola (Capillifera) hispida (Linné).
P *Vallonia*, sp.
Pupilla muscorum (Linné).
Ancylastrum fluviatile (Müller).
P *Limnæa pereger* (Müller).
P *Limnæa truncatula* (Müller).
Planorbis corneus (Linné).
Planorbis planorbis (Linné).
Bithynia tentaculata (Linné).
Valvata piscinalis (Müller).
P *Unio*, sp.
Corbicula fluminalis (Müller).
P *Sphærium*, sp.
Pisidium amnicum (Müller).

P = On the authority of Prestwich; not represented in the collection.

St. Edward's School: Playing-field.

Dr. Sandford has obtained *Corbicula fluminalis* (Müller) from this site.

Webb's Pit.

From this section three species have been obtained by Dr. Sandford:—*Fruticicola (Capillifera) hispida* (Linné), *Corbicula fluminalis* (Müller), and *Pisidium amnicum* (Müller).

Summertown. (Pit unknown.)

Eight species have been recorded from Pleistocene gravel at Summertown by Phillips.[2] The species recorded are

Goniodiscus rotundatus (Müller).
Pupilla muscorum (Linné).
Ancylus lacustris (Linné).
Limnæa pereger (Müller).
Bithynia tentaculata (Linné).
Valvata piscinalis (Müller).
Valvata cristata, Müller.
Pisidium amnicum (Müller).

These shells were probably of the same age as those found by Prestwich; but, since these examples are lost, the identifications cannot be checked.

Wolvercote.

The late A. M. Bell, in 1904, noted that eleven species of mollusca had been obtained from the gravels at Wolvercote; but the species were not enumerated.[3] These examples are now preserved in the Oxford University Museum; but the list has been extended by the work of Dr. K. S. Sandford, supplemented by

[1] Geol. Mag. 1882, pp. 49–50.
[2] 'Geology of Oxford & the Valley of the Thames' 1871, p. 467.
[3] Q. J. G. S. vol. lx (1904) p. 123.

additional examples collected by Mr. A. Wrigley. Seventeen species are now known, namely:—

Jacosta (Cernuella) virgata (Da Costa) 1 example.
Fruticicola (Capillifera) hispida (Linné) common.
Vallonia excentrica, Sterki, 3 examples.
Vallonia costata (Müller) 2 examples.
Helix nemoralis, Linné, 1 example.
Pupilla muscorum (Linné) 4 examples.
Ancylastrum fluviatile (Müller) 2 examples.
Limnæa palustris (Müller) 2 examples.
Bithynia tentaculata (Linné) 3 examples.
Valvata piscinalis (Müller) 6 examples.
Unio, sp.
Sphærium corneum (Linné) 2 valves.
Pisidium amnicum (Müller) 3 valves.
Pisidium henslowanum (Sheppard) 1 valve.
Pisidium subtruncatum, Malm, 2 valves.
Pisidium cinereum, Alder, 1 valve.
Pisidium nitidum, Jenyns, 1 valve.

Yarnton.

Phillips recorded three species of mollusca from the Pleistocene gravel at Yarnton,[1] and four species are preserved in the Oxford University Museum, namely:—*Pupilla muscorum* (Linné), *Limnæa pereger* (Müller), *Planorbis*, sp., and *Pisidium amnicum* (Müller). One species, *Fruticicola (Capillifera) hispida* (Linné), recorded by Phillips, is not represented.

Descriptions of New Species.

UNIO PRESTWICHI, sp. nov. (Pl. IX, figs. 2–6.)

Shell exceedingly thick and strong, ovate-oblong, cuneiform, much resembling typical *Unio tumidus*, Retz. in general outline, but with the posterior acuminate end more in the median axis. Umbones prominent, bearing two or three rows of W-shaped rugæ.

Hinge-line bent at the umbo, the anterior portion making an angle of 135° with the posterior (as against 145° in *U. tumidus*).

Anterior tooth of right valve broad at the umbonal end, tapering to a blunt point over the adductor-scar, exceedingly large and massive (15 × 7 mm., as contrasted with 11 × 3 mm. in *U. tumidus*), strongly and coarsely grooved transversely; terminating suddenly at the umbonal end beside a deep, coarsely roughened pit that receives one of the teeth of the opposite valve: the posterior lateral tooth is well developed, and almost straight.

In the left valve the two anterior teeth are correspondingly massive, and the pit at the base of the anterior one is very deep, and strongly, transversely grooved: the posterior lateral teeth are well developed, parallel for the greater part of their length, but approximate towards the umbo.

Muscle-scars deep and well marked. Anterior adductor-scar about as wide as long, pushed slightly towards the longitudinal

[1] 'Geology of Oxford & the Valley of the Thames' 1871, p. 467.

axis of the shell by the huge anterior tooth which overhangs it: dorsal margin straight, while the anterior and ventral margins form a sweeping curve, terminating in a spur-like projection which points towards the central area of the shell; the posterior margin proceeds thence dorsally in a convex curve. Posterior adductor-scar half as long again as wide, anterior margin straight, dorsal margin also straight at right angles to the anterior; the ventral margin starts similarly, then curves in, and joins the crescent-shaped convex curve of the posterior margin. The anterior pedal retractor-scar is a more or less circular pit in the ventral wall of the anterior tooth, its plane being consequently at right angles to that of the adductor. The anterior pedal protractor-scar is an elongate, curved triangle, situate on the inner side of the adductor-scar just above its spur-like projection, its base against the adductor-scar and concave side dorsal. The posterior pedal retractor-scar is small, pear-shaped, situate at the dorsal angle of the adductor.

Dimensions, calculated from the largest valve: length=90 mm.; height=50 mm.; thickness=35 mm.

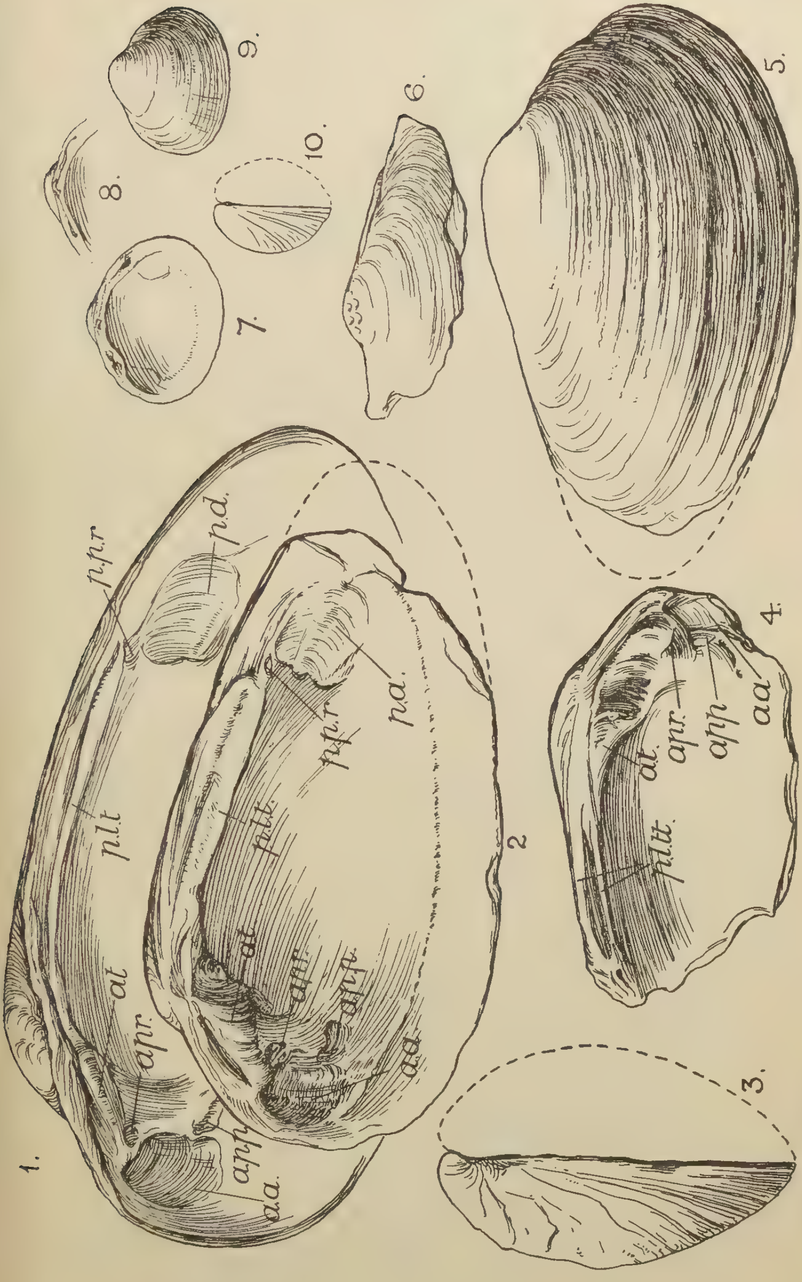
The outstanding feature of this new *Unio* is the enormous relative size of the anterior hinge-teeth. Greatly in excess of those of *Unio littoralis* Lamarck, they are even actually larger than those of the far bigger *U. auricularius* Spengler, dredged from the Thames at Barn Elms, that has more than twice the linear dimensions. While the dimensions of our largest and heaviest living *U. tumidus*, that have been quoted for comparison in our description, are evidence of the great difference between it and the new allied species.

Sphærium radleyense, sp. nov. (Pl. IX, figs. 7–10.)

Shell thick, strong, nearly complete, rounded oval, but slightly produced posteriorly below the longitudinal axis; umbones central, prominent; lines of growth irregular, not conspicuous.

Hinge—Right valve: hinge-plate deflected on either side of the cardinal area. This curvature is considerably accentuated in old and thickened specimens by the great development of the inner lateral teeth. Cardinal (*C. 3*) strongly flexed, becoming almost semicircular in the old valve, the distal ends of both *3 a* and *3 b* are thickened. Lateral teeth very strong, especially the inner teeth; *a. l. 1* stout and curved towards the interior of the shell, apex nearly median, thorn-like, the side remote from the cardinal being the more steeply incurved; *a. l. 3* very short and stout, its apex the same distance from the cardinal as *a. l. 1*; *p. l. 1* straighter and narrower than *a. l. 1*, apical point very much less pronounced, and the vertical ridge-curves on either side are nearly equal; *p. l. 2* shorter than *p. l. 1*, apex about the same distance from the cardinal as that of *p. l. 1*, width uniform, although in old specimens the cardinal end tends to thicken and coalesce with the outer shell-margin. Ligament-pit long, narrow, and deep.

Left valve: hinge-plate showing a continuous curve. Cardinal teeth: *C. 2* curves round from under the umbo across the hinge-



G. M. Woodward del.

UNIO PRESTWICHI, sp. nov. and SPHÆRIUM RADLEYENSE, sp. nov.

plate, joining the inner margin at a fairly high angle, and becoming sharply pointed; *C. 4* is long, straight, parallel with the hinge-line, rising to a sharp point opposite to *C. 2*, its base in the opposite direction becoming merged in that of the anterior lateral tooth; the lateral teeth are more prominent than those of the right valve, the anterior having the higher apex; the apices are situated towards the distal ends of the ridges, which are boldly curved on the cardinal, and steeply curved on the distal sides. Outline of apex curved away from the cardinal region.

Dimensions of largest whole (right) valve: length=13 mm.; height=10·5 mm.; thickness=9 mm.

The nearest ally of this new species is *Sphærium bulleni*, Kennard, from the Cromerian; but ours is a larger and rounder shell, and differs from that species in many important details, such as its less prominent, uncapped umbones, and in the hinge characters. Save in size, it is very distinct from the living *S. corneum*, Linné.

Conclusions.

The deposits from which these shells have been obtained belong to two periods: that at Wolvercote being of quite a different age from the remainder. The others represent one and the same stage. Unfortunately, the Wolvercote shells are a featureless group, all the species belonging to living forms; but, if we may judge from the form of *Fruticicola (Capillifera) hispida* (Linné), which is present, the Wolvercote deposit (that is, the channel) is probably older than the others. The shells are all well developed, and the climatic conditions in both stages were clearly similar to those of the present day, with the possibility that the later deposits may represent a slightly warmer phase. In regard to the correlation of these beds with those of the Lower Thames, it is unfortunate that there is only one fossiliferous deposit (namely, at Great Marlow), and in that case the list of species is very small. We are, however, justified in assuming that the Wolvercote deposit may be of the same age as the Ilford Brickearth, and the remainder of the same age as the Crayford beds.

EXPLANATION OF PLATE IX (facing p. 174).

[All the figures of *Unio* are of the natural size; those of *Sphærium* are somewhat enlarged.]

Fig. 1. *Unio tumidus* Retzius. Recent specimen for comparison.
2. —— *prestwichi*, sp. nov. Interior of right valve.
3. —— ——. End view of the same.
4. —— ——. Hinge of left valve of another individual.
5. —— ——. Exterior of right valve (fig. 2).
6. —— ——. Umbonal rugæ from another example.
7. *Sphærium radleyense*, sp. nov. Interior of right valve.
8. —— ——. Hinge of left valve of another individual.
9. —— ——. Exterior of right valve (fig. 7).
10. —— ——. End view of the same.

[*a.a.*=Anterior adductor scar; *a.p.p.*=Anterior pedal protractor scar; *a.p.r.*=Anterior pedal retractor scar; *p.a.*=Posterior adductor scar; *p.p.r.*=Posterior pedal retractor scar.]

Appendix IV.—Mineralogical Notes.
By Reginald Charles Spiller, B.A.

(A) Warp. Two samples.
(B) River-Silt. Three samples. } Samples examined.
(C) Oxford Clay. Two samples.

All collected from the brick-works at Wolvercote.

The Warp is a yellowish-brown sand with a small amount of yellowish mud, which was easily removed by washing to leave a clean light-brown sand. The sand was concentrated by panning, and separated with bromoform, giving an abundant crop of heavy minerals. Very little mica was seen in the washings, or in the concentrate. Sifting showed the presence of a small percentage of grains too large to pass a 30-mesh sieve. These consisted of quartz, subangular and rounded, ferruginous concretions (limonite?), chert-like fragments and lydian-stone. The minerals present in the lighter portion of the concentrate were quartz, felspar (microcline and orthoclase), and muscovite (scarce). The heavy minerals observed were garnet and zircon (abundant), tourmaline, rutile, staurolite, cyanite, epidote, and andalusite. Magnetite, ilmenite, and leucoxene were abundant.

No effervescence was observed on treatment with hydrochloric acid.

The River-Silt is a sandy clay, the proportion of clay apparently increasing with the depth from which the sample is taken. The clay is pale blue, with irregular yellow patches. On being washed and boiled, the clay breaks down into a yellow mud, leaving a light greyish sand which contains a good deal of mica. All the sand passed through a 30-mesh sieve. Concentration by panning and separation with bromoform gave an abundant crop of heavy minerals. The lighter portion contained subangular and rounded quartz, felspars (microcline and orthoclase), muscovite, and a few grains of chert. The heavy minerals observed were garnet and zircon (abundant), tourmaline, rutile, staurolite, cyanite, epidote, andalusite, and a grain of green hornblende. Magnetite, ilmenite, and leucoxene were abundant.

No effervescence was observed on treatment with hydrochloric acid.

The Oxford Clay is a stiff, plastic, dark-bluish clay, which gives a strong effervescence with hydrochloric acid. It takes some time to break up, boiling and treatment with hydrochloric acid facilitating the process. Washing leaves a small residue, which consists mainly of iron-pyrites with a little quartz, less orthoclase, and a very small percentage of heavy minerals. The heavy minerals observed were garnet, tourmaline, cyanite, zircon, staurolite, and rutile. No unaltered mica was seen.

Summary of results.

Warp.	*River-Silt.*	*Oxford Clay.*
Non-calcareous.	Non-calcareous.	Very calcareous.
No pyrites.	No pyrites.	Much pyrites.
Quartz very common.	Quartz very common.	Quartz very scarce.
Mica scarce.	Mica abundant.	Mica absent.
Felspars abundant.	Felspars abundant.	Felspars rare.
Minerals greater than 30-mesh. Quartz. Chert. Lydian-stone. Limonite.	Minerals greater than 30-mesh. None.	Minerals greater than 30-mesh. Pyrites.
Heavy minerals abundant.	Heavy minerals abundant.	Heavy minerals scarce.
Magnetite and ilmenite common.	Magnetite and ilmenite common.	No magnetite or ilmenite seen.

The warp and the river-silt would appear to have had a common origin, and their mineral constituents show that they were not derived from the Oxford Clay.

Discussion.

Prof. H. L. Hawkins expressed his appreciation of the great amount of painstaking work that had produced this paper, and congratulated the Author on the intelligible and consistent results that he had reached, as also on the lucid explanation of his conclusions. He (the speaker) had been especially interested in the evidence put forward to show the approximate agreement in curvature of the thalweg in all of the true terraces. This condition, together with the rough similarity in the level of terraces near Reading to those round Oxford, seemed to indicate that the gorge at Goring was as old-established a portion of the valley as any other part. The discovery of truly striated quartzites in the plateau-'gravel' was a point of great interest and gratification. He was glad that the Author had laid stress on the submerged gravel below the present flood-plain—its occurrence seemed to imply irregularity or oscillation in the uplift causing excavation of the valley, and previous comparable oscillations might have accounted for the duality of some of the terrace-gravels.

Prof. W. J. Sollas said that, among the many interesting results obtained by the Author, there was one conspicuous for its importance beyond the rest. This is the distinction of the gravels of the Second or Summertown Terrace into a lower division characterized by the cold Mammoth fauna and an upper by the warm *antiquus* fauna. It had been overlooked by all previous observers, and its discovery was the result of long-continued and patient investigation. Now that it was pointed out, it was obvious enough and could be traced over a wide area. The *antiquus* fauna here belongs to the first part of the Monastirian age (Riss/Würm), and the underlying Mammoth fauna must consequently be of Riss age.

The so-called Third or Wolvercote Terrace presents an interesting problem. The implements that afford any useful dates are Upper Acheulean which are Riss, and Lower Mousterian (Micoque) which are Riss/Würm, and thus of approximately the same age as the deposits of the Second Terrace.

The explanation would probably be found by considering the Wolvercote and Summertown deposits as the upper and lower members of what was originally a single terrace.

The Handborough Terrace, with a warm *antiquus* fauna which preceded that of the Second Terrace, is plainly Tyrrhenian, and elsewhere has been shown to contain, as it should, Chellean implements.

The speaker considered that the Author's work was one of the most valuable contributions that had as yet been made to the Pleistocene history of the valley of the Thames.

Mr. W. Johnson thought that the continuity of the terraces and the uniformity of the thalweg curves indicated uplifts which worked progressively upstream as far as the Oxford district. Should the plateau-drift above the Handborough Terrace prove to be glacial, it would have to be borne in mind when considering the Lower Thames Valley. The instances of 'trail' in the river-gravels were not necessarily to be associated with glacial periods; a series of severe winters would be sufficient to produce the sliding phenomena. Seeing that the 'pot-holes,' with their contained implements, are noticeably symmetrical and roughly in alignment, could they be due to artificial causes? It would be well if some agreement could be reached with respect to numbering the terraces; at present, it might be best to retain the English system, and number the series from the uppermost.

Mr. A. S. Kennard congratulated the Author on his paper, more particularly as it dealt with the Pleistocene geology of a somewhat neglected district. The mollusca which the Author had obtained from these deposits were of great importance, especially the Unionidæ, for one new species was represented. A new species of *Sphærium* was also present. It was hoped that further research would materially add to the list.

The President (Prof. A. C. Seward) warmly congratulated the Author on having successfully completed an important piece of work on a subject that is both difficult and interesting; he asked whether remains of Arctic plants had been found in the peat-beds of Wolvercote.

The Author said, in reply to Prof. Hawkins, that he had given in his charts the level of the base of each terrace with relation to the river-level. The whole of the levels throughout are those of the bottom of the deposit in question. He had noted no signs of differential movement in the Oxford district.

In reply to Prof. Sollas, he said that Mammoth-remains were extremely common in the bottom gravels of the Summertown-Radley Terrace, but there was only one instance yet known of Mammoth from the sunk channel.

In reply to Mr. Johnson, the Author said that perhaps swirl-holes would be a better term than pot-holes. The evidence was in favour of their formation by fluviatile agency, and there was nothing to show that they were of human origin. He had endeavoured to avoid the confusion which results from the numbering of river-terraces by using place-names, and he wished to emphasize the importance of that method.

In answer to the President, he said that the only peat yet found occurred in the Wolvercote Channel, and included a flora of temperate climate with two species now absent from England (one occurring in the Northern Highlands of Scotland, and the other in Central Europe and Siberia).

8. *The* AVONIAN *of the* TYTHERINGTON-TORTWORTH-WICKWAR RIDGE (GLOUCESTERSHIRE). By FREDERICK STRETTON WALLIS, Ph.D., F.G.S, (Read January 9th, 1924.)

[Abstract.]

THE Author describes and maps, in terms of Vaughan's system of zonal classification, the northern portion of the horseshoe-shaped wooded ridge of Avonian rocks which partly surrounds the synclinal basin of the Bristol Coalfield lying north-east of Bristol.

The area described links together the researches of two former papers,[1] and completes the Avonian zonal map of the horseshoe ridge.

The chief zonal characteristics may be summarized as follows:—

Cleistopora Zone.—Lithologically the zone consists of shales, grits, and thinly-bedded muddy limestones, with the usual fossils. The Bryozoa Bed (α) has been recognized, and the zonal fossil is unusually abundant in the Tytherington-Grovesend railway section.

Zaphrentis Zone.—Limestones of the 'Petit Granit' type, with intervening shales in Z_1, form the major part of the sequence. At the base of Z_1 in the Tytherington-Grovesend railway section is an interesting band of oolite. No chert has been found. Zaphrentids are very abundant, and the 'Z_2 Fish-Bed' occurs in the northern part of the area. Horizon γ cannot be differentiated, owing to the absence of *Caninia* immediately above the *konincki* subzone.

Syringothyris Zone.—The following sequence occurs in ascending order:—

(1) Thickly-bedded, nearly unfossiliferous, blue-grey dolomites (*laminosa* dolomites), apparently formed by the dolomitization of crinoidal limestones.
(2) A series of fossiliferous crinoidal limestones (Sub-Oolite Bed); non-oolitic in the lower, but oolitic in the upper portions.
(3) A thick bed of current-bedded white oolite (*Caninia* Oolite). This was probably immediately followed by a short period of subaërial denudation.
(4) Unfossiliferous thinly-bedded dolomites, with subordinate shales (*Caninia* Dolomites).

Series (2) and (4) are considerably thicker than their equivalents in the Avon Section.

Seminula Zone.—The zone consists of massive limestones, including examples of *Seminula* Pisolite, china-stones, and *Seminula* Oolites merging into sandstones and conglomerates of a 'Millstone Grit' phase of deposition. A calcareous sandstone

[1] Proc. Bristol Nat. Soc. ser. 4, vol. iv (1914) pp. 99–103 and Abs. Proc. Geol. Soc 1920–21, No. 1063, pp. 30–31.

(Firestone) occurs near the base of S_2 (formerly described from the top of S_1).

A calcareous development of the *Dibunophyllum* Zone is absent in the area described.

It is thus established, from the evidence of previous writers and that set forth in the present paper, that during Avonian times there was a progressive movement of the northern shore-line of Vaughan's 'South-Western Channel'[1] in a southerly direction. This movement is registered by noting the level in the Avonian sequence at which 'Millstone Grit' conditions were established.

The maximum thickness of the calcareous Avonian beds is only 1280 feet, as compared with 2540 feet in the Avon section.

The Tytherington-Grovesend railway provides a complete section of the Avonian rocks of the area.

[1] Rep. Brit. Assoc. (Manchester) 1915, pp. 429–31.

9. *The* AVONIAN *of the* WESTERN MENDIPS, *from the* CHEDDAR VALLEY RAILWAY *to the* SEA, WEST *of* BREAN DOWN. By Miss AGNES ELIZABETH BAMBER, M.Sc. (Communicated by Prof. S. H. REYNOLDS, Sc.D., F.G.S. Read January 9th, 1924.)

[Abstract.]

IN this paper a comparison is made between the Avonian of the Western Mendips and (*a*) the Avon Section and (*b*) the Burrington Combe section. The outcrops of the Carboniferous Limestone zones, classified according to the notation of the late Dr. A. Vaughan, have been mapped.

Levels from K_2 to S_1 are exposed in the area. The lithological and palæontological characters of the zones are described. Considerable faulting and folding occurs, more especially in the west of the region.

Comparison with the Avon Section.

K_2 subzone.—The lithological characters are similar to those of the Avon Section; but dolomitization is more general, and silicification more frequent.

Z zone.—Conditions of deposition were similar to, but not identical with, those of the Avon Section as shown by:—(*a*) the increased thickness of the zone, (*b*) the increased silicification, and (*c*) the greater number of species.

C zone.—Dolomitization is less than in the Avon Section. The *Caninia* Dolomites are represented by oolites and foraminiferal limestones, with subsidiary dolomites or dolomitized limestones. Oolites occur at the same level as the *Caninia* Oolites of the Avon; but neither china-stones nor calcitic mudstones occur in C_2.

S_1 subzone.—Dolomitized limestones and local china-stones occur on the same level as the china-stones and mudstones of the Avon Section. The china-stones are associated with oolites.

The following conclusions are deduced:—

(1) The detailed study of a small area of the Mendip country affords abundant proof of the usefulness of Vaughan's zonal classification in Carboniferous Limestones outside the Bristol area.

(2) The conclusions arrived at by Principal T. F. Sibly, and stated in his Mendip paper, have been confirmed.

(3) With the exception of the C_2–S_1 beds the lithological sequence in the Western Mendips is essentially similar to that of the Avon Section.

(4) *Modiola*-phase conditions in S_1 extended to the Western Mendips, but were not completely established there.

(5) The divergence from C_2–S_1 conditions of the Avon is slightly less in the Western Mendips than at Burrington.
(6) K_2, β, and Z_1, hitherto unrecorded from the area, are proved to be exposed.
(7) *Conocardium* sp. and *Spiriferina* (probably an early form of '*insculpta*') have been recorded from a level low in γ, and *Cyathophyllum* θ from the lowest beds of C_1.

The writer expresses her thanks, for the help which they have kindly given, to Prof. S. H. Reynolds, Dr. Stanley Smith, Dr. F. S. Wallis, Dr. F. J. North, and Miss H. Wood, M.Sc.

Discussion on the two foregoing Papers.

Dr. J. W. Evans enquired as to the age of the dip or oblique faulting. Was it part of the movements that gave rise to the folding, in other words, tear-faulting; or was it of a later date, and independent of the folding? In North Devon, and apparently in Cornwall, the north-west and south-east faulting appeared to be post-Triassic and probably of Tertiary age.

Dr. E. Greenly asked Miss Bamber whether the shattering which was confined to certain particular beds might possibly be contemporaneous, such as was found occasionally in the Thurso Flagstones and some other formations. And if not, then was the shattering accompanied by any signs of movement along the bedding-planes themselves?

Prof. A. Hubert Cox said that these papers contained many points of interest to himself, working as he was in a district not far removed from the areas covered by the two Authors. The 'firestone' mentioned by Dr. Wallis as occurring near the base of S_2 was of interest, in view of a record of 'firestone' associated with limestone below the 'Millstone Grit' of the Severn Tunnel. The speaker had recently enjoyed an opportunity of visiting the island of Steep Holme, and the lithological types there were similar to those mentioned by Miss Bamber as found in C_2 on Brean Down, even to the occurrence of similar 'gasteropod'-beds. At Barry, only a few miles distant, the limestones of the C Zone were almost all highly crinoidal. The underlying Z and C Beds resembled those described by Miss Bamber in containing abundant inter-bedded chert. He congratulated the Authors on the results of their work.

Prof. J. E. Marr and Prof. S. H. Reynolds also spoke.

Miss Bamber replied that the north-west and south-east faulting in the Elborough Hill district had not been traced in the surrounding Dolomitic Conglomerate and Trias, in which exposures are poor. The fault is probably pre-Triassic. Very little evidence had been observed to show whether the shattering of alternate beds in the north of Uphill Quarry was contemporaneous with, or subsequent to, deposition. The bedding-planes are very little exposed, but there seems to be some slickensiding on them.

10. *The* Lower Carboniferous Succession *in the* Settle District *and along the* Line *of the* Craven Faults.

By Prof. Edmund Johnston Garwood, Sc.D., F.R.S., F.G.S., and Miss Edith Goodyear, B.Sc., F.G.S. (Read May 10th, 1922.)

[Plates X–XXI.]

Contents.

I. Introduction.

The district which is the subject of the present communication has attracted the attention of geologists since the days of Playfair (46)[1] who, in his 'Illustrations of the Huttonian Theory' published in 1802, alludes to a visit that he paid, with Lord Webb Seymour, to Chapel-le-Dale and Thornton Force, and describes the unconformity between the Carboniferous Limestone and the underlying slates. Sedgwick (50), in a paper read before the Geological Society in 1831, described and illustrated the succession of the Carboniferous rocks which occupy the country between Penyghent and Kirkby Stephen. That paper, which shows a keen insight into the general structure of the district, was not printed in the Transactions until 1835.

The same year saw the publication of John Phillips's (44) classic work—'The Illustrations of the Geology of Yorkshire' the second part of which, 'The Mountain Limestone District', was issued in the following year. Phillips confined his attention to the lithological succession, and made no attempt to describe the distribution of the fossils, or to make use of them for the subdivision of the series, the palæontological portion of the work forming really an independent communication. It was impossible, however, that so careful an observer should fail to notice that certain fossils were more abundant at some horizons than at others,

[1] Numerals in parentheses refer to the Bibliography, § IX, p. 266.

and, although he does not allude to this fact in the work mentioned above, it is evident that it did not entirely escape his notice: for, in his Presidential Address (45, pp. xxxviii–xxxix) to the Geological Society in 1860, we find the following passage:—

'A palæontologist finds the whole Carboniferous period one, though in it are several zones distinguishable by the prevalence of a few types, and by the paucity or absence of others—the maximum of marine life being about the top of the Scar Limestone or the base of the Yoredale Series.'

He was thus evidently struck by the richly fossiliferous development which everywhere characterizes the Lower *Lonsdalia*-Beds at the base of D_2. The chief result of his work, however, was to show that, in the northern and central portions of the area under consideration, the Lower Scar Limestone is succeeded by an upper division, consisting of shales and sandstones with intercalated limestones, his 'Yoredale Series'. In the south-eastern portion of the district, on the other hand, between Fountains Fell and Greenhow Hill, he realized that the calcareous development, normally confined to the Lower Scar Limestone Series, persisted into the period during which his Yoredale Beds were being deposited in Wensleydale.

In the official memoir on the Burnley Coalfield (60), issued in 1875, a description is given of the Pendle Range and the Ribble Valley. The Lower Carboniferous deposits are here divided into two series:—The lower group (which includes the Clitheroe Limestone, the Shales-with-Limestone, and the Pendleside Limestone) is correlated tentatively with the Lower Scar or Great Scar Limestone north of the Faults; while the overlying Pendleside Grits and Bowland Shales are considered to be the equivalent of Phillips's Yoredale Beds.

Davis & Lees, in their account of West Yorkshire (13), published in 1878, while accepting the general subdivisions for the Carboniferous Series set out in the Geological Survey Memoir, include the Shales-with-Limestone in the Yoredale Series, and allude to the Pendleside Limestone under the term 'Yoredale Limestone'. They also note the development of dolomite in association with the faulting in the district.

Between the years 1889 and 1892 appeared the three sheets of the Geological Survey Map—Nos. 50, 60, & 61, comprising the districts of Ingleborough, Settle, and Pateley Bridge. These admirable maps, chiefly the work of Tiddeman and Dakyns, give a clear representation of the geological structure of the district, and have been used as a basis for the more detailed zonal maps that have been prepared for the present paper. Of the memoirs which should accompany these three sheets only one: namely, that relating to the Ingleborough sheet, has so far been published. This includes a brief account of the Lower Carboniferous succession, chiefly from a stratigraphical and lithological standpoint, as determined from certain selected exposures. Very little reference is made to the fauna, and no fossil lists are given. Several papers,

however, dealing with the areas included in Sheets 60 & 61 were published by Dakyns (4–10) between the years 1873 and 1899. R. H. Tiddeman, in a series of articles (61–70) published between 1888 and 1900, called attention to the difference in the character and thickness of the rocks on the two sides of the Craven Faults. He drew up a table of the succession south of the faults for the meeting of the British Association at Newcastle in 1889. This succession was afterwards adopted for the Survey maps. He also described the interesting structures to which he gave the name 'knoll-reefs', and discussed the origin and significance of their associated breccias. He expressed the opinion that the marked difference observable in the structure of the Carboniferous rocks on the two sides of the fault was due to disturbances which were taking place during their deposition.

In 1899 Prof. J. E. Marr (39), in his paper on Limestone Knolls in the Craven District, suggested that 'knoll'-structure could be produced by orogenic movements, but admitted that the typical 'knolls' that he had visited with Tiddeman did not furnish much direct information in support of his views. He also instituted a comparison between the deposits on the two sides of the faults, and pointed out that the fauna of the limestones north of the faults was little known, remarking (*op. cit.* p. 350) that

'the list of fossils collected from the Lower Scar Limestone north of the fault is meagre, and there are practically no fossil-lists of the faunas of the individual limestones that occur between the top of the Lower Scar Limestone and the base of the 'Millstone Grit'.

He suggests the following correlation for the series north and south of the fault (*loc. cit.*) :—

South Side.	North Side.
Millstone Grit.	Millstone Grit.
Bowland Shales.	Shales above Upper Scar Limestone.
Pendleside Limestone.	Upper Scar Limestone.
Shales-with-Limestones.	Yoredale Shales-with-Limestones.
Clitheroe Limestone.	Lower Scar Limestone.

Wheelton Hind, in 1901, in conjunction with Mr. J. A. Howe (28), published his views on the stratigraphical position of the Pendleside Group at Pendle Hill, defining that group as including the beds between the top of the Mountain Limestone and the series of grits known as the Millstone Grit. He considered that the lithological and the palæontological characters of these beds were entirely different from those of the Yoredale Series of Wensleydale and their homotaxial equivalents in the upper portion of the limestone massif elsewhere. He therefore placed them above the Yoredales, and included them in the Upper Carboniferous Series. These views he had already foreshadowed in his paper on the Yoredale Series, published in the 'Geological Magazine' for 1897 (22).

Since 1906, numerous papers relating to the district have been published by the late Prof. T. McK. Hughes, Mr. Cosmo Johns,

Dr. A. Wilmore, Prof. P. F. Kendall, and the late Dr. A. Vaughan, reference to which will be found in the Bibliography on p. 266.

In his interesting monograph on Ingleborough, Hughes (30) deals almost exclusively with the lithological succession, and evidently doubts the possibility of establishing definite faunal horizons in the Carboniferous rocks of the area, for he remarks (p. 300)—'There is at the present time a "boom" on zoning ..... The next stage will be a boom on "unzoning."'

Dr. Wilmore (75–79) has done valuable work in collecting from the rocks on the south side of the faults, and has suggested a broad correlation of the more important exposures with Vaughan's Bristol succession. The horizons, however, of these isolated exposures cannot be satisfactorily employed for correlation with the succession north of the faults, until detailed zonal mapping of the area has been undertaken.

Mr. Cosmo Johns (31–35) discusses several interesting problems connected with the succession north of the faults, notably the horizon of the Basement Conglomerate in Chapel-le-Dale, and the presence of minor dislocations in the area between the faults. He suggests a modified classification of the Yoredale Series, and supports Prof. Marr's correlation of the succession on the two sides of the faults.

At the British Association meeting at York (1906), a provisional correlation of the Carboniferous rocks of the Settle area with the succession in Westmorland was suggested by one of us (E. J. G., 17–18); but, in the absence of detailed mapping, this correlation could only be put forward on broad lines, and no southern limits could be assigned to the North-Western Province facies.

From a study of the works enumerated above it will be seen that the district still contained several problems of interest awaiting solution. Thus, the absence of detailed faunal lists from the succession north of the faults has been commented upon by several writers, and the exact position where the change from the northern to the southern type of development occurs had not been determined; while the presence of knoll-reef structures in the district south of the faults, and their absence on the north was attributed, on the one hand, to the original mode of deposition, and, on the other, to subsequent earth-movements.

In the present communication an attempt has been made, by detailed mapping of the faunal horizons, to obtain more reliable material for a fuller discussion of these outstanding problems.

The portion of the district which has been mapped in detail is bounded on the north by a line drawn east and west through Ribblehead, and on the south by the Middle Craven Fault: on the west by the Dent Fault, and on the east by the valley of the Skirfare (Littondale) and its continuation in the Upper Wharfe between Kilnsey and Grassington. Over this area definite faunal zones have been established, the general succession of the North-Western Province has been traced to its southernmost limit, and

the exact position where the change to the southern facies occurs has been ascertained. South of the Middle Craven Fault the southern type of development has been investigated over a small area in the district between Settle and Malham bordering on the fault, and an attempt has been made to correlate the succession here with the zonal development north of the faults.

A brief account of the easternmost exposure of the limestone massif between Greenhow Hill and Pateley Bridge is appended, in view of the evidence regarding the origin of the knoll-reef structures afforded by this district.

A word may be said here with regard to the nomenclature of the Craven Faults. Sedgwick (50) apparently recognized only one fault. John Phillips (44) appears to have been the first to name these faults in a published work. In the map accompanying his 'Illustrations of the Geology of Yorkshire' the northern fault is named the North Craven Fault, while his South Craven Fault begins north of Austwick, and is continued past Settle towards Malham.

R. H. Tiddeman mapped an additional fault running south-eastwards from Settle towards Skipton, of which he speaks as the South Craven Fault, and he included the whole of the line of faulting from Ingleton to Gordale, or beyond, in his Middle Craven Fault (62, p. 600). These terms are adopted by Prof. Marr in his paper on the Limestone Knolls (39, p. 351). He also calls attention to a further east-and-west fault lying north of the Geological Survey's Middle Craven Fault along the foot of Attermire and Beacon Scars, which he suggests may represent the main fault (39, p. 253).

Prof. P. F. Kendall speaks of Tiddeman's Middle Craven Fault as the Outer Craven Fault (36, pp. 54 & 56).

Other writers speak of one or other of the faults indifferently as the Great Fault, Hughes (30, p. 187) applying the term to the north and Dr. A. Wilmore to the Middle Fault. The last-named speaks of the Carboniferous Limestone south of the Craven Fault (76, p. 539), evidently alluding to Tiddeman's Middle Craven Fault.

In the present paper, in order to prevent confusion, we shall speak of the fault running from Ingleton to the neighbourhood of Skipton as the South Craven Fault, and limit the term Middle Craven Fault to the portion running from a little east of Settle, past Malham and Gordale, to the neighbourhood of Bordley Hall. The northern fault will be called the North Craven Fault.

During the progress of the work we have received much kind assistance from fellow-workers interested in the palæontology of the Carboniferous rocks: in particular, we wish to record our indebtedness to Mr. R. G. Carruthers, whose special knowledge of the Carboniferous cup-corals has been generously placed at our disposal, and who has named many of our specimens; to Miss Muir-Wood, who has devoted much time to the determination of

the Producti; to Mr. W. S. Bisat for naming several of the Goniatites; and to Miss Madeline Munro, who has assisted in the determination of the bryozoa. We also wish to express our thanks to Dr. W. D. Lang for kind criticism and advice in connexion with the palæontological notes which accompany this paper.

Finally, we gratefully acknowledge the assistance received by Miss Goodyear in connexion with this work, in the shape of a special grant from the Department of Industrial & Scientific Research.

II. The District North of the Faults.

This district comprises the area north of the Craven Faults and east of the Dent Fault, including the well-known eminences of Whernside, Ingleborough, and Penyghent. The faunal horizons have been carefully traced over the portion of this district lying east of Whernside as far north as a line passing east and west through Ribblehead, and their general disposition is shown on the accompanying map (Pl. XX). The area is entirely free from important disturbances, and the beds lie all but horizontally. The district forms the southern portion of the area recently described by Prof. J. E. Marr as the 'rigid block' (40).

Some difficulty occurs in the accurate representation of the zonal boundaries, owing to the superficial covering of drift. As, however, the object of the work is to prove the general continuation of the Westmorland succession into West Yorkshire, any inaccuracies in representing the outcrop of individual horizons in drift-covered areas will not affect the general conclusions.

The Lower Carboniferous rocks in the whole of the district north of the Craven Faults belong essentially to the North-Western Province facies, and form a direct continuation of the Westmorland succession: and the provisional correlation given by one of us at the meeting of the British Association at York in 1906 (18) has been found to hold generally over the area. The succession includes the horizons from the *Michelinia* Zone to the summit of the 'Main' or 'Great' Limestone, and appears to include the greater portion of Principal T. F. Sibly's D_3, of Derbyshire. The beds, therefore, belong entirely to the Viséan or upper portion of the Dinantian, as now usually defined. The highest limestones, however, which occur above the 'Main' Limestone in Wensleydale do not appear to be developed here. The fauna of the Lower *Dibunophyllum* sub-zone and that of the Upper Yoredales are scanty; and the Yoredale Beds generally (in particular the intercalated shales) show an attenuated development, when compared with Phillips's type-district in Wensleydale. The base of the succession also shows considerable variation locally, owing to overlap on to the irregular surface of the pre-Carboniferous floor, the *Michelinia* Zone, and sometimes the whole of the succession below the *Nematophyllum-minus* Beds is absent, especially over the district east of Crummack, although they reappear in Upper Wharfedale. Over this district also conglomerates are usually absent or insignificant, so that, at the period when the

N.-minus Beds were laid down, the Devonian continent must have been almost entirely submerged. This rapid submergence in *N.-minus* times was not limited to West Yorkshire, but is traceable also in Upper Teesdale and round the northern and western portion of the Lake District (15), pointing to the presence of an extensive peneplain over which submergence was practically contemporaneous. In one place only, namely, under Horton Lime-Works in Ribblesdale, have beds older than the *Michelinia* Zone of Westmorland been met with. Here a thin mudstone, containing a freshwater fauna with *Viviparus carbonarius* (21), was exposed during the opening of the quarry in 1889. The bed occupied a depression in the surface of the upturned Silurian slates, and appears to represent a deposit laid down in a pond on the surface of the Devonian continent. It is overlain by a thin black limestone, containing a marine fauna rich in lamellibranchs.

The *Michelinia* Zone.

The beds of this zone constitute the oldest marine Carboniferous rocks met with in the district under review.[1] They occur in the form of inliers bordering the sides of the valleys in Kingsdale, Chapel-le-Dale, and Wharfedale, and they must also presumably be present in Clapham Beck, but the index-fossil has not been found there.[2] The beds are now exposed at the surface, chiefly as the result of the denudation which followed the uplift on the north side of the North Craven Fault, although the exposure in Wharfedale is also due to the presence of a shallow anticlinal fold which crosses the river at about three-quarters of a mile south-south-east of Kilnsey Crag.

In the first four localities mentioned the beds rest on the denuded surface of the pre-Carboniferous rocks, and the zone includes the conglomerate which here usually occurs at the base of the Carboniferous System. These basement-beds were noticed by several of the older geologists, including Playfair (46), Sedgwick (50), and John Phillips (44); while in more recent times their detailed lithology has been studied by several writers, especially the sections in Chapel-le-Dale, which were fully described by T. McKenny Hughes (30). A few of the fossils which they contain were described by Mr. Cosmo Johns and the late Arthur Vaughan (31).

These beds undoubtedly represent a portion at least of the *Michelinia* Zone of Westmorland, though they are considerably reduced in thickness, and are difficult to separate from the base of the overlying zone. Where the beds are best developed, as in Kingsdale and at Nappa Scar, two horizons containing *Michelinia*

[1] Omitting the Lamellibranch-Bed which overlies the *Paludina* Mudstone at Horton.

[2] We should like to record here our thanks to Mr. J. A. Farrer, of Ingleborough, Clapham, for his kind permission to examine these beds in Clapham Beck.

may sometimes be distinguished: namely, a lower grey limestone, often false-bedded, containing numerous layers of pebbles of Silurian and Ingletonian rocks, and an upper darker and more earthy limestone from which pebbles are usually absent, except where these beds rest directly on the Lower Palæozoic floor.[1]

The lower grey limestone is well exposed above Pecca Falls (marked Old Quarry on the 6-inch map), where it contains remains of *Michelinia grandis* and *Chonetes carinata*. The corals and shells are in rather a fragmentary condition, as might be expected from the current-bedded character of the deposit. One large specimen of *M. grandis* may, however, be seen in the face of the quarry in an inverted position, a phenomenon not uncommon also in the Shap district. Several other species characteristic of the zone in Westmorland have been collected here. The occurrence of *Camarophoria isorhyncha* associated with *Chonetes carinata* is interesting, as in Westmorland and in North Lancashire *C. isorhyncha* is characteristic of the lower grey limestone, while *Ch. carinata* is confined to the upper earthy and shaly beds (=Arnside Beds). It is possible, therefore, that this lower grey limestone may represent both portions of the zone as developed in Westmorland. At Nappa Scar, under Norber Brow, the grey limestone reaches a thickness of about 50 feet. The lowest 5 feet are unfossiliferous; but the pebbly limestone above contains the same fauna as the beds below Thornton Force, including rare examples of *C. isorhyncha*. The fossils here are, on the whole, less fragmentary; but some of those embedded in the original matrix appear to occur in the form of pebbles. This would seem to point to the destruction of an earlier deposit subsequent to its consolidation, and the incorporation of fragments derived from it as pebbles in a deposit of slightly later date. Such an interpretation would account for the association of *C. isorhyncha* with *Ch. carinata* mentioned above. Whether this earlier deposit was laid down in the neighbourhood, and subsequently denuded as the result of oscillation of the sea-floor, or whether the pebbles were brought from outside the district it is not possible to determine. The upper dark limestone overlies the lower grey limestone wherever this is present; but in Chapel-le-Dale, in Jenkin Beck, and east of Norber Sike (Nappa Scar), it usually overlaps, so as to rest in places directly on the Lower Palæozoic floor. This upper limestone contains *M. grandis* and *Ch. carinata*, but these are associated with *Lithostrotion martini*, and would therefore appear to represent passage-beds up into the overlying *Productus corrugato-hemisphericus* Zone. In Westmorland these passage-beds are marked by a band containing *Zaphrentis enniskilleni*, *Clisiophyllum multiseptatum*, and *Cyathophyllum multilamellatum*, together with abundant specimens of *Caninia cylindrica*; and it

[1] Under the term 'Lower Palæozoic floor' we include the Ingletonian rocks described by Dr. R. H. Rastall (47), which, though possibly older, are assigned by the officers of the Geological Survey to the Ordovician.

is noteworthy that these forms also occur at the top of the *Michelinia* Zone in West Yorkshire, associated with specimens of *Clisiophyllum ingletonense* (73).

The following is a list of the fauna collected from the *Michelinia* Zone, which crops out in the district north of the faults:—

Species marked (*) are found in the lower grey limestone, and those marked (c) are fairly common.

Caninia cylindrica (Scouler).
Caninia subibicina M'Coy.
c *Clisiophyllum ingletonense* Vaughan.
Diphyphyllum aff. *lateseptatum* M'Coy.
c *Lithostrotion martini* Edwards & Haime.
* *Lophophyllum* sp.
*c *Michelinia grandis* M'Coy.
* *Zaphrentis* sp.
Zaphrentis konincki var. *kentensis* Garwood.
c *Syringopora geniculata* Phillips.

* *Athyris expansa* (Phillips).
*c *Chonetes carinata* Garwood.
Chonetes papilionacea Phillips.
* *Camarophoria isorhyncha* (Phillips).
c *Productus* cf. *corrugato-hemisphericus* Vaughan.
Overtonia fimbriata (Sowerby).
* '*Orthotetes*' sp.
* *Rhynchotreta* sp.
* *Syringothyris cuspidata* (Phillips).
Seminula cf. *ambigua* (Phillips).
* *Spirifer* sp.
Bellerophon cf. *costatus* Sowerby, as figured by L. G. de Koninck.

* *Nautilus* sp.
Leperditia sp.

The *Michelinia* Zone in Upper Wharfedale.

An interesting result of the zonal mapping of the area is the discovery of an inlier of the *Michelinia* Zone in the River Wharfe below Kilnsey Crag. The beds are here brought to the surface by an east-to-west anticlinal fold. The outcrop, which represents the northern limb of the anticline, forms a small cataract in the river, locally known as Mill Scar Lash. The lowest beds here consist of dark earthy limestone, and contain both *Michelinia grandis* and *Chonetes carinata*; while the beds above are characterized by abundant remains of *Lithostrotion martini*, representing the base of the overlying *Productus* Beds (S_1). The base of the Carboniferous is not seen here, and there is no conglomerate; but the underlying Lower Palæozoic rocks are probably not far off, and may occur in the river-bed close by, under the covering of drift and alluvium. The presence of an outcrop of Lower Palæozoic rocks in Upper Wharfedale is suggested by the occurrence of boulders of Lower Palæozoic grits and slates in the neighbourhood of Threshfield. Dakyns was also struck by the limited occurrence of these boulders, and suggested that Silurian deposits may occur at the base of Kilnsey Crag and in the lower part of Littondale where springs reach the surface (5).

The discovery of the *Michelinia* Zone in Wharfedale, which everywhere else east of the Dent Fault forms the lowest zone in the Carboniferous succession, renders it highly probable that Dakyns's suggestion of the occurrence of an outcrop of Lower

Palæozoic rocks in Upper Wharfedale in pre-Glacial times is correct.

The fact that the deposits of the *Michelinia* Zone are limited to the neighbourhood of the North Craven Fault points to the presence of an old shore-line at this period running in a general north-westerly and south-easterly direction, which passed through Chapel-le-Dale, east of Twistleton Dale House, through Crummack Dale north of Norber Sike, and skirted the southern end of Moughton. The remains of this shore-line can still be traced in the ridge of pre-Carboniferous rocks which in Chapel-le-Dale and Crummack Dale project up into the base of the Carboniferous Limestone. Everywhere north-east of this shore-line the *Michelinia* Beds are absent, and the oldest deposits met with resting on the pre-Carboniferous floor belong, as a rule, to the *Nematophyllum-minus* sub-zone.

South-west of this ridge the *Michelinia* sea spread uninterruptedly across the present line of the North Craven Fault in the neighbourhood of the Ribble Valley, as shown by the occurrence of beds of this age in the district between the faults, where they attain their greatest development. Between the Ribble and the Wharfe no rocks older than the *N.-minus* sub-zone occur, until we reach the inlier of the *Michelinia* Beds in Upper Wharfedale. North-west of Kingsdale the *Michelinia* Zone occurs at two points along the east side of the Dent Fault, as already described (19): namely, in Norgill and Pennyfarm Gill. Farther west the *Michelinia* sea spread over Westmorland and Furness, where the zone appears to have reached its maximum development.

The beds containing *M. grandis* in West Yorkshire north of the Craven Faults may be correlated generally with the δ horizon of the South-Western Province.

The *Productus corrugato-hemisphericus* Zone.

The beds of this zone in West Yorkshire succeed the *Michelinia* Zone, where it is present, but locally form the lowest portion of the limestone massif where the *Michelinia* Beds are absent, when they rest directly upon the Lower Palæozoic floor.

As in Westmorland, three divisions may be recognized: namely, the Gastropod Beds (S_1) at the base; a middle division with *Cyrtina carbonaria*; and an upper division with *Nematophyllum minus* (S_2). The middle division is, however, very poorly developed in West Yorkshire, although the index-fossil has been found in a few places. The upper division, on the other hand, is, as a rule, well developed, except locally, where ridges of pre-Carboniferous rocks remained above the surface of the sea during the earlier part of the period. As in Westmorland, the term '*Seminula* Zone' is inappropriate for these beds in West Yorkshire; for this genus is very rarely met with except near the base, and we prefer to retain the appellation '*Productus corrugato-hemisphericus* Zone', so as to mark the affinity of this horizon with beds of the Westmorland

succession. There is, however, no doubt that these beds are the equivalent of the 'S' Zone of the Bristol district.

The Gastropod Beds.—These beds form a succession of hard dark limestones, with earthy and shaly partings, which directly succeed the beds of the *Michelinia* Zone wherever these are present. They are well exposed above Thornton Force, and also along both flanks of Chapel-le-Dale and under Norber Brow. They are here taken as including the passage-beds containing *Clisiophyllum ingletonense* mentioned above, which represent the *Clisiophyllum* Band of Arnside and Blackstone Point. The beds are characterized by well-preserved specimens of *Athyris expansa*, *Schellwienella crenistria*, and small early forms of *Chonetes papilionacea*, together with occasional specimens of *Bellerophon hiulcus*. They usually include a thin layer containing *Seminula* a short distance above their base; but, as in Westmorland, there is no species that is particularly characteristic of this sub-zone, and, although it is convenient to retain the name 'Gastropod Beds' applied to this horizon farther north, it is not especially applicable to this horizon in West Yorkshire.

The upper limit of the sub-zone is difficult to determine, as dark limestones continue up into the overlying beds. It has been found convenient, therefore, to represent all the beds of the zone by a single colour on the map. The average thickness of the sub-zone may be taken at about 100 feet, but in Chapel-le-Dale this will probably include a portion of the overlying beds.

The *Cyrtina-carbonaria* Sub-zone.—The development of this sub-zone in West Yorkshire is, as already stated, singularly poor. It is interesting, however, to be able to record the occurrence of this zonal species in the area east of the Dent Fault, as it emphasizes the general similarity of the succession with that of Westmorland. No specimen has been found in Chapel-le-Dale or Kingsdale, but the species has been collected in three localities farther east: namely, at Austwick Beck Head in Crummack Dale, and also on both sides of Ribblesdale near Horton. In Crummack Dale it occurs in a thinly-bedded fossiliferous layer immediately above the base of the Carboniferous Limestone; while, on the west side of the Ribble, it has been found in a crushed condition in a thin layer of calcareous shale, which rests on the Silurian rocks in the floor of Horton Lime-Quarry. On the east side of the Ribble well-preserved specimens occur, associated with a small *Productus*, *Seminula*, and '*Orthotetes*', in a compact black limestone some 30 feet above the conglomerate in Dub Cote Gill; and the same band has also been met with half a mile farther north at Douk Gill, and in the old quarry nearer Dub Cote Farm. In all these localities the *Cyrtina-carbonaria* Beds are immediately succeeded by dark grey limestone containing specimens of *Nematophyllum minus*. These three exposures occur along a line running nearly due east and west, and occupy a narrow valley-like depression

excavated in the floor of the Lower Palæozoic rocks. This depression probably formed a strait which was connected with the sea on the west, in which the *Cyrtina-carbonaria* Beds were being laid down in the Ravenstonedale, Shap, and Kendal districts. If continued to the west of Crummack Dale along the same line, this depression would pass south of Ingleton; and this fact may account for the absence of *Cyrtina carbonaria* from Chapel-le-Dale and Kingsdale.

The *Nematophyllum-minus* Sub-zone.—As stated elsewhere (19, p. 472), the horizon from which Llwydd obtained his type-specimen of *Lithostrotion basaltiforme* is unknown, and the name is applicable to several species of prismatic *Lithostrotion.* For zonal purposes, therefore, we will refer to the species which characterizes this portion of the succession throughout Westmorland and West Yorkshire as *Nematophyllum minus* M'Coy, since M'Coy's type was obtained from this horizon on Scout Scar, Kendal, and there can be no doubt as to the species intended, or as to the horizon at which it occurs. This sub-zone forms one of the most widespread horizons of the succession in West Yorkshire, for it was at this period that the final submergence of the pre-Carboniferous land-surface took place. In Kingsdale, Chapel-le-Dale, and on Norber Brow it succeeds the Gastropod Beds (S_1); while in Ribblesdale and at the head of Crummack Dale, it rests locally upon the *Cyrtina-carbonaria* Beds which occupy the depression described above. Everywhere else, however, where the base of the sub-zone is exposed north of the faults, it overlaps on to the denuded surface of the Lower Palæozoic rocks. This relation is well seen at the head of Chapel-le-Dale, near God's Bridge, and round the east side of Crummack Dale; while in Ribblesdale it is well exposed round the foot of Moughton Scar and at Coomb's Quarry. East of Ribblesdale it again forms the base of the Carboniferous in Silverdale near Sannet Hall, and also in Gordale Beck above New Street Gate. In all these places the base of the Carboniferous is marked by small reef-like growths of *Nematophyllum minus.* The thickness of the sub-zone, where it rests upon the *Cyrtina-carbonaria* Beds and reaches its full development, is about 230 feet. Lithologically the beds consist of two portions: the lower being composed of dark-grey limestone, which is succeeded by a pale-grey or buff-coloured rock. The transition between the two portions is abrupt, and at first sight would appear to mark an important change in the succession; but their fauna is similar, and *Nematophyllum minus* occurs in both. The darker colour of the lower beds appears to be due to the presence of land in the immediate neighbourhood supplying fine detrital material, and this view is confirmed by the presence of layers of small pebbles of Silurian rock which occur up to 20 feet above the base of the deposit in Coomb's Quarry. The pale buff-coloured limestone above, on the other hand, appears to have been deposited in clearer

water after all land had been submerged in the neighbourhood, and shows no sign of admixture of terrigenous material; while Silurian pebbles are absent, the beds being made up of fine comminuted calcareous débris, foraminifera, etc., in which the larger fossils are embedded. The best exposures of these beds occur on the west side of Ribblesdale, in Horton and Coomb's Quarries and in the Scars above.

The lower dark limestone here contains abundant specimens of *Nematophyllum minus* and numerous examples of *Bellerophon costatus*. The dark limestone has a thickness of 30 feet, while the overlying buff-coloured limestone, measured up to the Porcellanous Bed described below, is 170 feet thick, giving a total thickness for the *N.-minus* Beds of 200 feet. On the east side of the Ribble, above Dub Cote, the thickness is again 200 feet; while in Chapel-le-Dale, above Twistleton Dale Hall, where the full development of the sub-zone is observed, it reaches a thickness of 220 to 230 feet. The fauna of this sub-zone is not rich, but is similar to that which characterizes the same horizon in Westmorland, *Productus corrugato-hemisphericus* occurring throughout; while a large form of *Macrochilina* has been found in these beds, both at Horton and in Upper Gordale. About 25 to 30 feet below the summit occurs a layer containing large specimens of *Chonetes papilionacea* associated with the highest specimens of *N. minus*, here characterized by the large size of the corallites. This layer appears to be the attenuated representative of the beds containing abundant *Ch. papilionacea* on Arnside Knott.

The *Dibunophyllum* Zone.

The Porcellanous Bed.—The line of division between the *Productus corrugato-hemisphericus* Zone and the overlying *Dibunophyllum* Zone is not so well marked in Yorkshire as it is in Westmorland, where the presence of a definite faunal horizon ('the Bryozoa Band') affords a good datum-line for mapping. This band has not been met with east of the Dent Fault, and the two zones therefore merge one into the other, the difficulty of separating them being increased by the scarcity of fossils in the lower portion of the D_1 sub-zone. Fortunately, however, the lithological characters afford a means of determining the position of the junction-line in many parts of the Yorkshire area. In the Shap district the Bryozoa Band is associated with a marked 'porcellanous' bed or china-stone (calcite-mudstone of Mr. E. E. L. Dixon), characterized by definite macroscopic and microscopic characters and especially by an abundance of *Calcisphereæ* (19, p. 473). An exactly similar bed of china-stone, 2 to 3 feet thick, occurs in West Yorkshire in the district north of the faults. It lies 25 to 30 feet above the layer of *Chonetes papilionacea* mentioned already. This Porcellanous Bed lies about 300 feet above the top of the *Michelinia* Zone in Kingsdale, so that the maximum

thickness of the *P. corrugato-hemisphericus* Zone in West Yorkshire may be taken as 300 feet. It is well exposed on both sides of Chapel-le-Dale, at Crina Bottom, round the head of Crummack Dale, and on the west side of Ribblesdale between Coomb's Quarry and Selside. It can also be traced for some distance along the east side of Ribblesdale near Horton, and farther north at Low Birkwith; but it is poorly developed round the southern end of Moughton and in Silverdale. The underlying layer with *Ch. papilionacea* can, however, be identified in both these localities, and the base of the *Dibunophyllum* Zone is, therefore, represented on the map (Pl. XX) as being 25 feet above this layer. This band, in addition to its porcellanous texture, is characterized by the infilling of the shrinkage-cracks and cavities with slightly darker crystalline calcite.[1]

Above Horton Quarry the beds contain young specimens of *Nautilus* and *Orthoceras*, together with numerous small gastropods, the interiors of which are filled with a similar deposit of crystalline calcite. Under the microscope the rock is seen to be composed of very fine-grained crystalline mud, in which are embedded abundant remains of *Calcispheræ* and occasional foraminifera, some of the *Calcispheræ* retaining traces of reticulate tests (19, pl. xlvii, fig. 4).

As usual in the North of England, this zone may be divided lithologically into two portions—a lower massive limestone and an upper series of limestones, sandstones, and shales—the 'Yoredale' Series of Phillips. These two lithological divisions correspond in general to a subdivision on broad palæontological grounds, the lower massive limestone being characterized by the occurrence of *Cyathophyllum murchisoni* throughout; while the upper complex represents the period during which *Lonsdalia floriformis* and *Productus giganteus* and their variants flourished in the district.

This zone includes D_1 and D_2 of the Avon sequence, and at least a portion of D_3 of Derbyshire. The beds in Derbyshire, however, were laid down under somewhat different conditions, and it is not possible, at present, to say exactly where the line between D_2 and D_3 should be drawn in West Yorkshire; although, from general considerations, it appears to lie about the horizon of the *Orionastræa* Band, or slightly higher. In the circumstances, we consider it best to treat the Yoredale Beds and the underlying Lower *Lonsdalia* Beds as a unit, under the denomination *Lonsdalia* sub-zone. In the case of the lower division again, although there can be no doubt regarding its equivalence to the Lower *Dibunophyllum* sub-zone of the South-Western and North-Western Provinces, there is so remarkable an absence of the index-fossil over the greater part of the district that we prefer to speak of these beds in West Yorkshire as the equivalent of the *Cyathophyllum-murchisoni* sub-zone of Westmorland.

[1] A somewhat similar structure in the Avon section has been referred to a boring animal (49, p. 457).

The *Dibunophyllum* Zone occupies a large part of the area north of the North Craven Fault, especially in the central and northern regions; and the famous hills of the district—Whernside, Ingleborough, Penyghent, and Fountains Fell, are formed of beds of this age.

The *Cyathophyllum-murchisoni* Sub-zone (D_1).—The beds of this sub-zone form the upper part of the limestone massif throughout the district. Owing to their purity and freedom from insoluble material and to the presence of master-joints, they give rise to the well-known 'Karst' conditions: that is, limestone pavements, grikes, and pot-holes, for which the region is celebrated (11, 30, 83).[1] These conditions are admirably displayed on the plateau surrounding the base of Ingleborough, and it is a noteworthy fact that the majority of the pots which swallow the surface-drainage from the Yoredale Beds above are situated in or close to the *Girvanella* nodular band that marks the summit of this sub-zone. This is the case at Alum Pot Gill, Long Kin, Gaping Ghyll, Mere Gill, and the pots dedicated to Tatham's Wife and Braithwaite's Wife. Again, on Penyghent, Hunt Pot, Hull Pot, Jackdaw Hole, and Browgill Pot are all situated at the junction of D_1 and D_2. The base of the sub-zone is taken at the Porcellanous Bed described above, while the summit lies immediately below the *Girvanella* nodular band, which everywhere in the North of England forms the base of D_2. The average thickness of the sub-zone is 250 to 280 feet, and the beds consist, for the greater part, of a compact, blue-grey limestone with a slightly purplish tint, which varies in depth of colour from bed to bed. In places, especially in the upper portion, the rock takes on the character of a pseudo-breccia, and may become 'spotted'; but this feature is not so pronounced as in the case of beds of this sub-zone in Westmorland (19, p. 475). Shaly beds are, as a rule, entirely absent; but a thin band of ferruginous mudstone resembling underclay occurs at this horizon (in the old quarries on the Midland Railway, near Ribblehead Station), a short distance above the *Cyrtina-septosa* Band, while a similar mudstone crops out at the head of the small beck immediately east of the Station Inn (11).

On the whole, however, the lithological characters are generally similar to those of the beds of D_1 age west and north of the Dent Fault, and the fauna is also similar but exceedingly scanty (20, p. 24 *et seqq.*). Yet towards the summit a band occurs, often crowded with fossils, which is especially characterized by the abundance of specimens of *Cyrtina septosa* and *Chonetes comoides*.

The *Cyrtina-septosa* Band occurs about 80 to 100 feet below the summit of the sub-zone. It may be directly correlated with the band containing *C. septosa* and *Ch. comoides* in the Shap, Grange, and Silverdale districts (19, p. 479). The index-fossil appears to range through some 25 to 30 feet of rock; but it is

[1] See especially (11) pp. 34–40.

only in the highest layer that it becomes really abundant, and it is this horizon that has been traced on the accompanying map (Pl. XX). Occasionally, a second fossiliferous layer may occur about 20 feet below the top of the band; but, as a rule, there is no difficulty in locating the higher horizon in the field. As in Westmorland, the index-fossil is associated with abundant remains of *Chonetes comoides*, *Cyathophyllum murchisoni*, *Dibunophyllum vaughani* (*Dibunophyllum* θ Vaughan, p. 259), and large spherical masses of *Alveolites capillaris*: a few examples of *Productus striatus* have also been collected, while *P. hemisphericus* and *Syringopora* spp. are usually abundant. The band often gives rise to terraces, capped by a small escarpment formed of the overlying massive pseudo-breccia bed, and is then frequently obscured by turf. Typical exposures may be seen round Sulber Gate and on the flats north of it, also on both sides of Chapel-le-Dale; but perhaps the best exposure of all occurs in the old quarry on the side of Horton Lane under Penyghent, about two-thirds of a mile south-west of Hull Pot. The band has, however, been identified over practically the whole area north of the faults. In Upper Wharfedale this band is frequently dolomitized, and the fossils are then preserved as casts. This is the case at Mr. Delany's quarry at Threshfield, where the rock crops out close to the North Craven Fault, and forms one of the best beds of dolomite in the North of England. Again, above Kettlewell there is a good exposure at this horizon in dolomite on the 1075-foot contour due east of the village. The band crosses the Wharfe at Ghaistrills Strid half a mile north-north-west of Grassington railway-station; but it is not well exposed in this area, and has not been mapped in detail. There can, however, be no doubt that it occupies its usual horizon throughout the district, the easternmost exposure met with being at Greenhow Hill, about 4 miles west of Pateley Bridge. The upper beds of the D_1 sub-zone, overlying the *Cyrtina-septosa* Band, have an average thickness of 60 to 80 feet, and consist usually of massive beds of pseudo-breccia separated by thinly-bedded crinoidal limestone. These massive beds give rise to a succession of low escarpments, which are well seen on the north-western flank of Ingleborough above the Hill Inn, and along Twistleton Scars. They also occur round the southern end of Penyghent and elsewhere in the district, where they form the well-known limestone-pavement traversed by grikes. For a short distance above the *Cyrtina-septosa* Band the beds are as a rule fairly fossiliferous, and *Productus hemisphericus* and *P.* cf. *maximus*[1] are locally abundant.[2]

[1] See (19) p. 570.

[2] It is probable that the type species of *P. hemisphericus*, figured in Sowerby's 'Mineral Conchology' fig. 328, came from this horizon in the Settle district. For a general list of the fossils occurring in this sub-zone the reader may consult the table given in (20) p. 24.

The *Lonsdalia-floriformis* (or *Productus-giganteus*) Sub-zone.—This division in West Yorkshire includes the whole of Phillips's 'Yoredale Series', together with a small thickness of the underlying limestone massif, coloured as 'Great Scar' Limestone on the Geological Survey maps. Something may be said here regarding the actual horizon which is taken as the base of the Yoredale Series in West Yorkshire on the Geological Survey maps. Over the Ingleborough and Penyghent district limestone deposits persisted into Lower D_2 times, so that the *Girvanella* Band and the Lower *Lonsdalia* Beds are frequently included with the Great Scar Limestone. Confusion is introduced by the fact that the top of the Great Scar Limestone is not mapped as a constant horizon, even in the same district. Thus, round Ingleborough, the top of the massif at the northern end is taken at about the level of the *Girvanella* Band; while, at Mere Gill, and Alum Pot Gill and elsewhere, it is taken at the base of the shale underlying the Hardraw Scar Limestone: and, on the west of Penyghent, even this latter limestone is included in the Great Scar Limestone massif on the Geological Survey Map.

The *Girvanella* Nodular Band.—This important band has now been traced everywhere in the North of England, forming a definite horizon at the base of D_2. It appears to mark the change in conditions which took place at this period, when elevation occurred and the sea became suitable for the growth of calcareous algæ.

In West Yorkshire this band also marks the base of D_2, as it does in Westmorland and Lancashire. On account of its value as a stratigraphical horizon, it has been traced over the greater part of the area north of the faults, and its outcrop has been marked on the accompanying map (Pl. XX). It is identical in all respects with the band which has been described as occurring at this horizon in the area north and west of the Dent Fault (19, p. 482). It was however noticed in Hull Pot Gill and below Farrer's Shooting Box on the eastern flank of Ingleborough by T. McKenny Hughes, who alluded to the characteristic *Girvanella* nodules as 'almond-shaped concretions'. These nodules are limited to a few feet of rock, and occur crowded together in certain layers. The true *Girvanella* Band is composed of a compact black limestone, with occasional thin shaly partings almost devoid of other fossils, and weathers into a characteristic grey cement-stone unlike the beds immediately associated with it. The nodules, when freshly broken, usually show a deep brown colour, and porcellanous texture characteristic of these algal growths; but, after weathering, they become pale grey, and show well-marked concentric banding, forming conspicuous objects on the weathered surfaces. Under the microscope the *Girvanella* tubes are usually found to include two species of notably different size, often arranged concentrically, and frequently stained by iron salts. Although the band is exposed over a large part of the area, the following localities may be specially

mentioned:—on the western flank of Penyghent in Hull Pot Gill just on the edge of the pot, and also in the dry gill immediately west of it. Here the band is especially well exposed, and thin sections of the nodules from this locality usually show well-preserved *Girvanella* tubes (Pl. XIX, figs. 1 & 2). Other good exposures occur under Penyghent in Jackdaw Hole, and in Brow Gill Pot farther north. Round the north-western flank of Ingleborough, between Crina Bottom and Gauber High Pasture, the band is exposed almost continuously; also in Alum Pot Beck, a little below Farrer's Shooting Box. Again, it is seen south of Gaping Ghyll, and in one or two pots above Runscar north of Ribblehead, in Ellerback Gill, and immediately north of Bruntscar Farm on the south-western flank of Whernside. In the eastern portion of the district the band has not been mapped in detail, but it is well developed in upper Wharfedale.

The *Girvanella* Band is succeeded by a few feet of thinly-bedded dark crinoidal limestone, which in turn is overlain by more massive beds of cement-stone and earthy shale containing *Productus giganteus*, *Lonsdalia floriformis*, and *Cyathophyllum regium*, which we may define as the 'Lower *Lonsdalia* Beds'. This series of beds which, round Ingleborough, is about 30 feet thick, varies somewhat in detail from place to place. On the whole, however, the general character of the Lower *Lonsdalia* Beds is similar throughout the district north of the faults, and resembles very closely the development at this horizon in Westmorland. The fauna is also similar, but is decidedly richer and more abundant in West Yorkshire. In addition to the three species mentioned above, *Productus sulcatus* is especially characteristic; while reef-building corals, notably *Lithostrotion junceum*, *L. maccoyanum*, and *Syringopora* spp., together with species of *Dibunophyllum*, *Aulophyllum*, and *Lophophyllum* occur abundantly.

The following is a list of the fauna collected from the Lower *Lonsdalia* Beds north of the Craven Faults:—

Girvanella.
Nodules containing 'bean'-shaped organisms.

Alveolites sp.
Amplexus sp. nov.
Aulophyllum fungites Edwards & Haime.
Aulophyllum concentricum sp. nov.
Caninia juddi Thomson.
Carcinophyllum cf. *vaughani* Salée.
Carcinophyllum sp.
Cyathophyllum cf. *murchisoni* Edwards & Haime; very large form.
Cyathophyllum regium Phillips.
Dibunophyllum aff. *matlockense* Sibly.
Dibunophyllum rhodophylloides sp. nov.
Dibunophyllum aff. *rugosum* (M'Coy).
Dibunophyllum splendens Thomson.
Dibunophyllum aff. *turbinatum* M'Coy.
Diphyphyllum gracile M'Coy.
Diphyphyllum lateseptatum M'Coy.
Lithostrotion junceum Fleming.
Lithostrotion maccoyanum Edwards & Haime.
Lithostrotion portlocki (Bronn); good epitheca preserved.
Lonsdalia floriformis (Fleming).
Lophophyllum magnificum Thomson & Nicholson.
Michelinia sp., cf. *gracilis* Smythe.
Rhodophyllum distans sp. nov.
Syringopora geniculata Phillips.
Syringopora reticulata Goldfuss.

Zaphrentis aff. *costata* M'Coy.
Zaphrentis costata M'Coy.
Zaphrentis densa Carruthers.
Zaphrentis aff. *enniskilleni* Edwards & Haime.
Zaphrentis omaliusi Edwards & Haime.
Zaphrentis sp. nov. 1.
Zaphrentis sp. nov. 2.
Zaphrentis sp. nov. 3.

Cyathocrinus sp.

Athyris obtusa M'Coy.
Athyris lamellosa L'Eveillé.
Athyris planosulcata Phillips.
Athyris roysii L'Eveillé.
Camarophoria crumena Martin.
Chonetes buchiana L. G. de Koninck.
Leptæna analoga (Phillips).
Productus giganteus Martin.
Productus, latissimoid form.
Productus margaritaceus Phillips.
Productus setosus Phillips.
Productus sulcatus Sowerby.
Productus tissingtonensis Sibly.
Buxtonia scabricula (Martin).
Pugnax pleurodon (Phillips).
Pugnax trilatera L. G. de Koninck.
Retzia radialis (Phillips).
Rhipidomella michelini (L'Eveillé).
Schizophoria resupinata Martin; not common.
Spirifer cinctus Keyserling.
Spirifer crassus L. G. de Koninck.
Spirifer bisulcatus Sowerby.
Spirifer integricostus Phillips.
Spiriferina insculpta Phillips.

Fenestella plebeia M'Coy.
Fistulipora sp.

Edmondia sp.
Modiola megaloba M'Coy.
Sanguinolites sp.
Sedgwickia sp.

Bellerophon spp.
Loxonema rugiferum (Phillips).

Nautilus spp.
Orthoceras sp.

Griffithides acanthiceps H. Woodward.
Trilobite-fragments.

Good exposures in this horizon are found scattered over the district, and in general occur in the localities cited above in course of description of the *Girvanella* Band. The sections in Hull Pot and Hunt Pot under Penyghent have been described by McKenny Hughes in his paper on Ingleborough, as also the section in the gill below Farrer's Shooting-Box on the southern flank of Ingleborough. The exposures in Hunt Pot and Hull Pot Beck are two of the best in the district, and many of the species enumerated in the foregoing list were obtained from them. An interesting section also occurs at the top of this series in the western tributary of Hunt Pot Gill, immediately north of the wall. Here we find a bed almost entirely composed of corals, the most abundant species being a long cylindrical form of *Dibunophyllum*, associated with *Lophophyllum* and reeflike masses of *Diphyphyllum*; while a very large variety of *Cyathophyllum murchisoni* also occurs. The new species of cup-coral (*Rhodophyllum distans*) described in the palæontological section of this paper (p. 261) was also first obtained from this exposure, another specimen being subsequently obtained from the exposure of these beds in the beck above Old Ing. The section in Hull Pot Beck is notable for the abundance and size of the specimens of *Productus giganteus*, and has long been known as a collecting-ground for this fossil, while a similar exposure occurs farther north-west near Black Dub Moss. On the north-western flank of Ingleborough the best exposures occur in Keld Bank Sike, and at the springs and in the pot-hole on Gauber High Pasture, half a mile south of Ribblehead Station. Here the highest

layers, both at the spring and round the edge of the pot, are composed of yellow rubbly crinoidal limestone containing rolled and fragmental shells. This bed contains numerous specimens of *Zaphrentis densa* and *Z.* aff. *enniskilleni*, together with three species of *Zaphrentis* which differ from any species hitherto described, one of these being the species mentioned below as occurring in nodules, and figured by the late Arthur Vaughan in his paper on Loughshinny.

Concretionary nodules.—Wherever the Lower *Lonsdalia* Beds are well exposed they are found to contain concretionary nodules, which are usually confined to the shaly partings. They vary in size up to one and a half inches in diameter, and are approximately spherical, with a slightly lobate surface. Except for their larger size, they resemble the *Girvanella* nodules at the base of D_2. In many localities, notably at Keld Sike and Gauber High Pasture, these concretions are formed round small cup-corals, especially *Zaphrentis costata, Z. omaliusi*, and an unnamed species of *Zaphrentis*, which Mr. R. G. Carruthers has identified for us as a form common in the shales above the Derbyshire massif and identical with a form figured by Vaughan from Loughshinny (41, pl. xlix, fig. 2). A small species of *Amplexus* also occurs n these nodules, which does not appear to have been hitherto described.

In thin sections the nodules proved to be built up of roughly concentric layers, composed partly of iron pyrites, partly of a compact calcareous deposit with a structure somewhat resembling *Aphralysia*, while small patches of *Girvanella* tubes may occasionally be seen. The most interesting constituents, however, are certain small 'bean'- or rather 'banana'-shaped organisms, which occur in aggregates, and lie with their concave margins facing the central nucleus. Long sections of these show transverse septa up to five in number. These organisms appear to be bounded by definite walls, and are frequently impregnated with iron pyrites (Pl. XIX, fig. 3). Their exact nature has not been determined: they may possibly be of vegetable origin, but they do not resemble calcareous algæ. On the other hand, they present a certain resemblance to foraminifera; their definite concentric grouping is, however, difficult to account for. The different layers mentioned above are usually arranged in a roughly concentric manner. They are mentioned here chiefly on account of their stratigraphical value, as they have not been met with below this horizon. They appear to range up into the overlying Yoredale Beds, and Mr. R. G. S. Hudson has recently shown to us specimens which he has collected from a slightly higher horizon in Wensleydale. Some years ago very similar nodules, in which however, the structure is more obscure, were noticed by one of us in, or slightly above, the Oxford Limestone in Northumberland.

The succession above the Lower *Lonsdalia* Beds is well exposed on the north-western flank of Ingleborough, and in the eastern

tributary of Cam Beck. At Fairweather Springs, a mile south-south-west of Ribblehead Railway-Station, we find the following section:—

	Thickness in feet.
Limestone with chert (*Orionastræa* Band)	—
Platy limestone, containing *Productus latissimus*	12
Shales	12
Massive iron-stained limestone	8
Compact splintery limestone (Lamellibranch-Bed)	5
Compact limestone, passing down into iron-stained cement-stone and shale	16
Shale yielding *Aulophyllum*, etc.	12
Not seen	10
Lower *Lonsdalia* Beds	30
Girvanella Band	—

The most interesting feature here is the development about the middle of the section of a highly fossiliferous bed, forming a small escarpment, which is unusually rich in lamellibranchs. The following is a list of species collected from this bed:—

Hyalostelia sp.: masses of anchoring spines.
Pemmatites sp.

Aulophyllum fungites Edwards & Haime.
Dibunophyllum sp.
Diphyphyllum lateseptatum M'Coy.
Lithostrotion portlocki (Bronn).
Lonsdalia floriformis (Fleming).
Lophophyllum sp.

Athyris planosulcata (Phillips).
Athyris roysii L'Eveillé.
Athyris sp.
Chonetes hardrensis Phillips.
'*Orthotetes*' spp.
Productus edelburgensis Phillips.
Productus hemisphericus group.
Productus longispinus group.
Productus pugilis Phillips.
Productus sulcatus Sowerby.
Productus tissingtonensis Sibly.
Productus spp.
Productus spines in abundance.
Buxtonia scabricula (Martin).
Pustula elegans (Davreux).
Pustula punctata (Martin).
Reticularia lineata (Martin).
Rhipidomella michelini (L'Eveillé).
Spirifer bisulcatus Sowerby.
Spirifer (?) crassus L. G. de Koninck.
Spirifer (Fusella) trigonalis Martin.
Schizophoria resupinata (Martin): large form.

Fenestella sp.
Polypora sp.
Ptilopora sp.
Synocladia sp.
Dyscritella sp.

Aviculopecten dissimilis (Fleming).
Allorisma variabilis (M'Coy).
Edmondia laminata (Phillips).
Edmondia maccoyii Hind.
Edmondia sulcata (Phillips).
Edmondia sp.
Eumicrotis hemisphericus (Phillips).
Lithodomus sp.
Pinna flabelliformis (Martin).
Protoschizodus æquilateralis (M'Coy).
Protoschizodus fragilis (M'Coy).
Pseudamusium redesdalense Hind.
Solenomya costellata M'Coy.
Sanguinolites plicatus (Portlock).
Sanguinolites subcarinatus M'Coy.
Sanguinolites tricostatus (Portlock).

Fish-tooth.

The occurrence of sponge-remains (*Pemmatites*, see Pl. XVIII, fig. 2) and also of anchoring spines is interesting, as the same form occurs at approximately the same horizon below the *Orionastræa* Band between the faults near Bordley, but has not been met with at other horizons in West Yorkshire. Among the

brachiopods *Schizophoria resupinata* is found abundantly, and of large size, comparable with forms of this species which occur at Sellet Mill near Kirkby Lonsdale at the same horizon, and at Scaleber in the Shales-with-Limestones on the south side of the fault. Attention may also be drawn to the occurrence here of a varietal form of *Productus pugilis* which occurs in considerable abundance: this fossil is limited to that portion of the succession which intervenes between the summit of the Lower *Lonsdalia* Beds and the *Orionastræa* Band, and appears to have a wide geographical range at this horizon. It occurs abundantly in the eastern tributary of Cam Beck, and in Cow Gill near Bordley, and elsewhere in West Yorkshire; it is also found at the same horizon at Sellet Mill. We have met with it too in the Shales-with-Limestones in Kirkby Malham Beck, south of the Middle Craven Fault. It may, therefore, be regarded as an important zonal index near the summit of D_2 (Pl. XVIII, fig. 1). The most striking feature of the fauna, however, is the abundance and variety of the lamellibranchs which represent an unique development at this horizon in Yorkshire. Of these the most noteworthy is *Pinna flabelliformis*, which occurs in considerable numbers. Elsewhere it has only been noted on the east side of Ingleborough in Fell Close Sike, and between the faults near Bordley, where it again occurs at the same horizon; but it is also recorded by McKenny Hughes from Hull Pot Beck. South of the faults it occurs in the knoll-reefs at Cracoe.

The shale-bed overlying the Lamellibranch Limestone is not well exposed, and has not yielded any forms of special interest. The platy limestone and calcareous shale which underlie the *Orionastræa* Band are essentially of the horizon of *Productus latissimus*, although examples of this fossil may occur as low down as the Lower *Lonsdalia* Beds, and may pass up into beds above the *Orionastræa* Band. *P. edelburgensis* also occurs at this horizon, some specimens attaining a large size, while *Aulophyllum fungites* is usually plentiful. McKenny Hughes records the occurrence of plants in a brown earthy limestone, which must be about the horizon of the base of these beds. This shaly limestone containing *P. latissimus*, together with the underlying shales, should (according to the Geological Survey mapping) represent the upper portion of the shales which, together with the overlying sandstone, form the face of the cliff at Hardraw Force in Wensleydale. The Lamellibranch Bed and the shale beneath it would then be the equivalent of the lower portion of the Hardraw Shale, which at Mill Gill and at Hardraw contains abundant examples of *Posidonomya becheri*. This species has not, however, so far been met with in the Ingleborough district, although it occurs at about the same horizon near Budle in Northumberland.

The *Orionastræa* Band is a cherty limestone, and is the Hardraw Scar Limestone of the Geological Survey map of Ingleborough.

Specimens of *Orionastræa phillipsi* are rare and badly preserved, and are limited to the highest layers. They occur in thin sheets interstratified with tabular chert-layers, and are frequently themselves silicified. They are, therefore, difficult to detect, and it is not perhaps surprising that this coral should hitherto have escaped observation in this district; indeed, it was only discovered by us on Ingleborough as the result of a careful search, after this band had proved to be characteristic of the district between the faults, where it is more fully developed. In the Westmorland district only one specimen has so far been obtained: namely, in High Cup Gill, and though not *in situ*, it probably came from the Scar Limestone, which appears to represent the same horizon.[1]

The best exposure on Ingleborough is seen in Mere Close Gill; but badly-preserved specimens have also been found at this horizon in Tatham's Wife Hole, on the downthrow side of the fault, and again in South House Moor Beck above its junction with Alum Pot Beck. Fossils are scarce at this horizon on Ingleborough, but *Lithostrotion junceum* is eminently characteristic of this band, the form that occurs here being notable for the small size of the corallites, which do not reach 2 mm. in diameter. Occasional specimens of a large *Caninia* also occur. This cherty *Orionastræa* Band is mapped by the Geological Survey as the equivalent of the Hardraw Scar Limestone of Wensleydale, a correlation which is not entirely satisfactory, as the latter contains *Lonsdalia*, but does not contain either chert or *Orionastræa*; while *Productus edelburgensis* and *P. latissimus* occur in the shale above, though not (so far as we are aware) in the shale below. Everywhere in the district north of the faults, as in Upper Wharfedale above Kettlewell, *O. phillipsi* occurs both in the upper portion of the Simonstone Limestone and below the Dirt Pot Grit, and still more abundantly in the lower portion of the Middle Limestone above it. It seems possible, therefore, that, when allowance is made for the reduction in the thickness of the beds on Ingleborough, the *Orionastræa* Band on Ingleborough represents the Simonstone Limestone of Wensleydale, and the Hardraw Scar Limestone may be represented by the horizon of the Lamellibranch Bed of Fairweather Springs. The section in the eastern tributary of Cam Beck, above and below Far House Barn already mentioned, is one of the best exposures of the Lower Yoredale Beds in the district. Here may be seen a nearly continuous section, from the *Girvanella* Band in Cam Beck to the shales and sandstones overlying the *Orionastræa* Band. The Lower *Lonsdalia* Beds crop out in the lower portion of the tributary and on the left bank of Cam Beck. The shale exposed in the small gully which enters this tributary on the right bank evidently represents the shale at the base of Fairweather Springs. The overlying beds which correspond to the Lamellibranch Limestone crop out at the waterfall below Far

[1] *O. phillipsi* has recently been collected by Mr. R. G. S. Hudson from the Simonstone and Middle Limestones in Wensleydale. The specimens from Derbyshire and Wales all occur, so far as is known, in D_2 (55).

House Barn, and are remarkable for the abundant specimens of *Productus pugilis*. The lamellibranch fauna which is so notable a feature of this horizon at Fairweather Springs is, however, absent. The *Productus-latissimus* Shale comes on above Far House Barn (Shooting Box), where it forms the face of the waterfall; while the overlying limestone (the Hardraw Limestone of the Geological Survey Map) should represent the *Orionastræa* Band. That bed does not, however, exhibit the usual cherty character here, neither has *Orionastræa* been found to occur in it. The overlying shale is notable, on account of the interesting crinoidal remains which it contains. The late Mr. Philip Roscoe, of Hampstead, who collected extensively from this bed, kindly furnished us with the following list, which he drew up in conjunction with Dr. F. A. Bather:—*Platycrinus* 2 spp., *Eurycrinus* sp., *Rhodocrinus* sp., *Gynerocrinus* sp., *Cyathocrinus* sp., *Onchyocrinus* sp., and *Zeacrinus* sp.

On Ingleborough the *Orionastræa* Band is overlain by a few feet of shale, succeeded by a massive sandstone which forms the waterfall in Mere Gill, and contains obscure plant-remains. Some of the layers exhibit curious stellate impressions on the bedding-planes, which at first sight appear to resemble badly-preserved casts of *Orionastræa*. This resemblance is due to the presence of slight depressions, round which the radial grooves are arranged, and to the curiously regular spacing of these astræiform impressions. The centre of each depression, which continues downwards as a vertical tube, is filled with a bleached deposit of siliceous material. The origin of the structure is obscure: it may represent worm-burrows, or possibly gas-bubbles discharged through wet sand at low tide.

The higher Yoredale limestones below the Main Limestone are not well exposed on Ingleborough, Whernside, and Penyghent; but sections showing two well-developed limestones above the *Orionastræa* Band, called the Simonstone Limestone and the Middle Limestone by the Geological Survey, occur in places. Some of these are described in the Survey Memoir on Ingleborough (11) and in McKenny Hughes's paper (30), wherein he notes the absence of the Underset and Three-Yard Limestones of Teesdale. These limestones, so far as we have been able to examine them, are singularly devoid of fossils in comparison with their equivalents in Wensleydale; such organisms as do occur present no special points of interest or zonal significance.

The Main or Upper Scar Limestone, also known as the Twelve-Fathom Limestone, is a highly crinoidal deposit, well exposed round the south side of Ingleborough and on Simon Fell. According to McKenny Hughes, the limestone is let down on the southern flank of the summit of Ingleborough by a continuation of the west-north-west and east-south-east fault already mentioned in Tatham's Wife Hole; but this seems unlikely, as

the downthrow in the latter exposure is northwards. If the fault suggested by McKenny Hughes exists it must be a separate dislocation, or a slipping over the calcareous sandstone beneath. The thickness of the Main Limestone on Ingleborough is about 50 feet, and it maintains the same thickness on Whernside and Greenfield south of Old Ing. Farther north, however, on High Wold and on Widdale Fell, it has increased to nearly double this thickness, and increases still more as we reach Wensleydale. In the Ingleborough district this limestone is poor in fossils other than crinoid-ossicles; but specimens of *Productus giganteus* var. are fairly abundant near Lord's Seat on Simon Fell, while *P. muricatus* is not uncommon on High Wold south of Widdale Fell: beyond these, however, we have only succeeded in collecting a few badly preserved forms:—*Dibunophyllum* sp., *Athyris planosulcata*, *Spirifer bisulcatus*, *Productus pugilis*, and *Schizophoria resupinata*.

The following list is given on the authority of McKenny Hughes (30, p. 296):—

Thamniscus dubius (King) var. *carbonarius* (Vine).
Spirifer ovalis (Phillips).
Spirifer trigonalis (Martin).
Spirifer trigonalis var., with a smooth medial rib.
Athyris planosulcata.
Athyris ambigua.
Rhynchonella cordiformis (Sowerby).
Camarophoria crumena (Martin).
Productus scabriculus.
Productus semireticulatus.
Productus pustulosus (?).
Leptæna rhomboidalis var. *analoga*.
Streptorhynchus (Orthotetes) crenistria (Phillips).
Dielasma sacculum (Martin).
Capulus neritoides.
Pterinopecten sp.

Hughes also records *Brachymetopus* as occurring here, but states that this requires verification.

This list, although a meagre one, is interesting, as the majority of the forms recorded are characteristic of a high horizon in the Yoredale Series, and occur also in the Cracoe reefs south of the faults; so far as they go, they support Prof. J. E. Marr's correlation of the Main Limestone of Ingleborough with the Knoll Reefs of Cracoe and the Pendleside Limestone. The poverty of the fauna on Ingleborough is in marked contrast with that of the Wensleydale district, where *Lonsdalia floriformis* (and other species of *Lonsdalia*), together with *Caninia* and a rich general fauna, occur.

III. The District between the Faults.

This district contains a strip of Lower Carboniferous rocks bounded on the north by the North Craven Fault, on the west by the South Craven Fault, and on the south by the Middle Craven Fault.

The northern portion, between the Dent Fault and Clapham, averages less than half a mile in width, but broadens out, on reaching the Ribble valley, to a width of $2\frac{1}{2}$ miles. From here it

gradually contracts again as it is followed eastwards, and near Bordley the width is reduced to less than a mile.

The general succession in this area belongs essentially to the northern facies, and may be regarded as constituting the southern margin of the North-Western Province. At the same time, modifications occur, especially in the higher beds, which are most pronounced in the eastern portion of the district. Thus, the Lower *Dibunophyllum* Sub-zone is even poorer in fossils than in the district north of the faults; while the Yoredale Beds become more calcareous and crinoidal, and true shale is almost completely absent. Certain changes also occur about the middle of D_2: to wit, the development of a series of thinly-bedded crinoidal limestones yielding *Athyris lamellosa*. This series, in certain localities, contains a rich and specialized fauna; while the summit of the series is marked by a thin but constant layer, containing abundant remains of *Stenophragma* and *Dyscritella*. To this series we shall refer for convenience as 'the Bryozoa Series'. The *Orionastræa* Band, which is poorly represented round Ingleborough, becomes more pronounced here, and reaches its fullest development between Malham and Bordley. The most notable feature, however, in this strip between the faults is the occurrence of patches of rock east of Settle which differ essentially, both in their lithological characters and in their faunal contents, from any known horizon in the North-Western Province succession, but resemble closely the Knoll-Reef Limestones and the Bowland Shales of the southern facies.

The district between the faults may, for convenience of description, be divided into two portions: namely, a western portion lying between the Dent Fault and the Ribble, and an eastern portion stretching from the Ribble to the Wharfe.

District between the Faults—West of the Ribble.

The general structure of this portion of the strip is that of a flat anticlinal fold, the dip being towards the faults on both margins. The beds here include the succession from the *Michelinia* Zone as far as the summit of the *Orionastræa* Band. The *Michelinia* Zone is exposed only in a few isolated inliers, while the Yoredale Beds have been removed by denudation from the greater portion of the district. The succession, up to and including the Lower *Lonsdalia* Beds, is similar in its development to that already described in the area north of the faults, and does not call for detailed description, the general outcrop of the different zones and bands being shown on the map (Pl. XXI). There are, however, a few special features which merit a brief description.

The *Michelinia* Zone.—The fact that rocks belonging to this zone appear at all at the surface in the strip of country between the faults is interesting and somewhat unexpected, in view of their position on the downthrow side of the North Craven Fault. The beds crop out in four separate exposures, namely:—

(1) at Newby Cote, $1\frac{1}{2}$ miles north-west of Clapham; (2) near Stainforth Bridge in the River Ribble; (3) in the tunnel and railway-cutting near Taitlands House; and (4) in the railway-cutting immediately west of Langcliffe.

The first of these exposures occurs close to the South Craven Fault, while the two next occur near the margin of the North Craven Fault. In all these cases the outcrops appear to be due to the presence of dome-like folds developed near the margin of the faults, and they may be compared with similar structures which occur on a more pronounced scale near Greenhow at the eastern end of the district, to be described later. The occurrence of this structure in rocks belonging to the normal North-Western succession is not devoid of interest, in connexion with the origin of the reef-knolls which form such conspicuous features in the Malham and Cracoe districts south of the faults.

(1) At Fell Gate Quarry, Newby Cote, only the higher layers of the *Michelinia* Zone are exposed, as the upper portion of the black limestone seen in the quarry belongs to the base of S_1. *Chonetes carinata* has not been found here; but the base is not seen, and there is no conglomerate. Specimens of *Michelinia grandis* are occasionally exposed about half-way up the quarry-face, while *Athyris expansa* is plentiful throughout the lower portion. A layer of *Seminula* occurs above the *Michelinia* Bed, and the shaly decalcified beds at the top of the quarry are highly fossiliferous, containing *Zaphrentis enniskilleni*, *Z. konincki* var. *kentensis*, *Cyathophyllum multilamellatum*, *Lithostrotion*, etc., an assemblage which characterizes the passage-beds of C–S_1 elsewhere.

(2) In the inlier at Stainforth Bridge we find the most complete development of the *Michelinia* Zone exposed anywhere in the Settle district. Most of the species characteristic of the *Michelinia* Zone at Arnside may be collected here, including *Zaphrentis konincki*, *Caninia subibicina*, and *Lophophyllum meathopense*. The beds are brought to the surface by an elongated dome, the major axis of which, striking west-north-westwards, crosses the Ribble about 100 yards below the bridge, close to the Force. The lowest 20 feet, which form the cliff below the Force, consist of unfossiliferous grey limestone. Above this the beds are darker, with earthy partings, and contain examples of *Michelinia grandis*; while 10 feet higher occurs a bed yielding abundant specimens of *Chonetes carinata*.

The lowest examples of *Lithostrotion* are found about 25 feet above this, and we may take this horizon as marking the base of S_1, giving a total thickness for the *Michelinia* Zone here of 55 to 60 feet. At the northern end of the section, above the bridge, the beds are succeeded by a few feet of the Lower *Productus* Zone (S_1). The beds here are much crushed and dolomitized against the North Craven Fault, and contain bipyramidal quartz-crystals. At the southern end of the dome the beds dip under drift and alluvium; but dark limestones, belonging to the base of S_1, and containing

Zaphrentis enniskilleni, are brought to the surface at intervals by a series of gentle folds which extend as far as Langcliffe Paper-Mill. Below Robin Hood's Mill these rocks form a cliff on the right bank: here the beds are dolomitized, and a spring issues which appears to mark the position of a fault. The base of the Carboniferous is nowhere exposed in the Ribble section, and no true conglomerate occurs; but a few decomposed pebbles of Silurian rocks are found in the lowest grey limestone at Stainforth Force, and other fragments are scattered sparingly through the beds above. It is probable, therefore, that the base of the limestone seen at the Force is not far above the Silurian floor, although it must be remembered that similar small fragments of Silurian slates occur abundantly up to 30 feet above the base in Horton Quarry.

(3) The third exposure of the *Michelinia* Zone is seen in the railway-cutting and tunnel close to Taitlands House, a quarter of a mile south of Stainforth, and forms the eastern continuation of the Stainforth-Bridge dome. The beds in the tunnel, which constitute the core of the anticline, belong to the *Michelinia* Zone, and contain *M. grandis* and *Chonetes carinata*; while the beds in the cutting belong to the overlying passage-beds (C_2–S_1). The débris from the tunnel may be examined in the old spoil-heaps lying between the railway and the road, and afford good material for collecting, while specimens of *Chonetes carinata* may be seen in the neighbouring walls. The only point in connexion with this exposure that requires special mention is the occurrence of certain encrusting growths formed round specimens of *Lophophyllum* and other organic fragments. Under the microscope this encrusting material is seen to be composed of two layers: namely, an inner layer formed by the growth of a species of *Koninckopora* (probably *K. inflata* L. G. de Koninck), and an outer layer showing concentric laminæ which under the microscope exhibit a structure resembling '*Spongiostroma*'. Similar structures occur at the same horizon (C_2–S_1) on the right bank of the Ribble, above Stainforth Bridge. Hitherto the bryozoon forming these encrustations has only been recorded from the North-Western Province in the Kendal district, where it occurs at the same horizon. Elsewhere it is recorded (also from C_2) by Arthur Vaughan, from Tickenham near Clevedon. It is further reported from D_2 at Wetton (Derbyshire) and from Stebden Knoll, Cracoe.

(4) The only other undoubted exposure of the *Michelinia* Zone in the Ribble valley occurs in the railway-cutting immediately west of Langcliffe village. Here a gentle anticlinal fold again brings the *Chonetes-carinata* Beds to the surface, and blocks containing the index-fossil may be seen in the railway boundary-wall running into Settle. No definite exposure of the zone occurs in the Ribble near Settle, although two outcrops of a dark limestone are seen: one under Settle Bridge, and the other at Queen's Rock opposite King's Mill. The beds at the bridge contain no determinable fossils, while at Queen's Rock the beds are much crushed and impregnated by veins, owing to their proximity to the South

Craven Fault. Both these exposures must be low down in the series, as the nearest outcrops (seen some distance above) occur in the Lower *Productus* Beds (S_1).

The *Productus* Zone (S) and the Lower *Dibunophyllum* Subzone (D_1) exhibit the normal type of development characteristic of the North-Western Province. The Porcellanous Bed is absent or but feebly developed, so that it is not always possible to trace the exact junction of these two zones in the field. *Nematophyllum minus*, however, occurs in several places, and the *Cyrtina-septosa* Band is generally well developed. Consequently, with the experience gained in tracing the junction in the district on the north, a fair approximation to the true position may be made, and the line of junction shown on the map (Pl. XXI) is sufficiently accurate for our purpose as showing the general succession in the district. The best continuous section of these beds is seen in Meal Bank Quarry, along the right bank of the Greta, near Ingleton, and on Storrs Common above the left bank of that river. The lowest 60 feet of beds exposed here near the North Craven Fault belong to the *Nematophyllum-minus* Beds (S_2), and specimens of the index-fossil may be collected from the northern end of the quarry and in the corresponding exposure on the left bank of the stream. The beds here show the usual anticlinal disposition. Near the North Craven Fault the beds dip northwards, but soon arch over and dip at a gradually increasing angle (20° to 30°) southwards as they approach the South Craven Fault, against which they are highly dolomitized. The lowest beds of D_1 are almost devoid of fossils, and their exact junction with the underlying zone is difficult to determine. The section extends up to the *Cyrtina-septosa* Band and a short distance above it, but terminates against the South Craven Fault before reaching beds of D_2 age. The *Cyrtina* Band forms a slight step in the floor, and can be traced up into the face of the quarry.

The section has been complicated by certain dislocations which appear to be in the nature of thrust-planes making a low angle with the horizon, one of which may be seen near the summit of the quarry close to the South Craven Fault (Pl. XIII, fig. 1).

There are in the quarry-section two features of especial interest in connexion with the stratigraphical succession. Of these, the first is the presence of a highly fossiliferous bed of nodular limestone, some 8 feet thick, which lies about 30 feet below the lower *Cyrtina-septosa* Band. It is exposed in the face of the quarry about 180 yards from the South Craven Fault, and is also well seen in the isolated blocks which have been left during the quarrying operations (Pl. XI, fig. 2). This bed is of interest, for several reasons. Prof. J. E. Marr, in his paper on the Limestone Knolls of Craven (39, p. 352) mentions a bed in Meal Bank Quarry which he regards as a crush-breccia due to earth-movements, and it probably is this bed. Although the rocks in the quarry have undoubtedly been much affected by earth-stresses, and Prof. Marr's contention in this respect is correct, there can be no doubt that the

peculiar structure of the nodular bed is original, and not due to subsequent brecciation. This view is based on the fact that the bed, which is highly fossiliferous, may be definitely correlated with a similar bed that occurs at the same horizon in Trowbarrow Quarry, near Silverdale Station (19, p. 513).

The fossils, which consist chiefly of corals and large Producti, show signs of partial corrosion, and are thickly coated with a curious concretionary deposit of lime, so that, on weathering, the rock presents a strikingly nodular appearance. Some of these nodules show a radial and fibrous structure, and the general aspect of the deposit recalls some of the well-known concretionary beds in the Magnesian Limestone of Durham. The bed passes down into a 'spotted' limestone similar to the beds so characteristic of the upper portion of D_1 in Westmorland (19, p. 513). The general character of this nodular bed appears to point to a temporary cessation of mechanical deposition, during which the fossils were exposed to the action of sea-water, the lime thus removed being precipitated in the form of concretionary incrustations.[1] In view of the generally unfossiliferous character of the beds of the D_1 zone in West Yorkshire we append a list of fossils collected from this bed (see Pl. XI, fig. 2):—

Aulophyllum concentricum sp. nov.
Aulophyllum fungites mut. *pachyendothecum* (Thomson).
Alveolites capillaris (Phillips).
Caninia sp. nov.
Carcinophyllum θ Vaughan.
Carcinophyllum spp.
Clisiophyllum sp.
Cyathophyllum murchisoni Edwards & Haime.
Dibunophyllum bristolense nom. nov.
Dibunophyllum vaughani nom. nov.
Dibunophyllum aspidiophylloides sp. nov.
Dibunophyllum sp. approaching *Histiophyllum dicki* Thomson.
Lithostrotion junceum Fleming.
Lithostrotion maccoyanum Edwards & Haime.
Lithostrotion martini Edwards & Haime.
Syringopora sp.
Zaphrentis cf. *delanouei* Edwards & Haime.

Chonetes cf. *compressa* Sibly.
Leptæna analoga (Phillips).
Productus maximus M'Coy.
Productus subgiganteus var. of *giganteus* (Martin).
Productus sp.

Fistulipora sp.

Orthoceras sp.; fragments of a very large form.

Trilobite-fragments.

Another interesting feature of this section is the presence of a wedge-shaped block of coal associated with underclay, apparently interbedded with the limestone, which forms a projection in the face of the quarry about 45 feet below the 'nodular' bed described above. This patch of coal was first noted by Mr. C. Ricketts in 1869, who remarks (49, p. 36):—

'the existence of a bed of impure coal, about 2 feet thick, exposed in the Ingleton limestone-quarries . . . probably indicating that upheaval and subsequent denudation has to some extent occurred previous to its deposition, and that therefore the present thickness of the Carboniferous Limestone, nearly 600 feet, does not represent the whole time during which the formation was in progress.'

[1] Compare the concretionary manganese-nodules dredged by the late Sir John Murray from a depth of 10 fathoms in the Firth of Clyde.

Prof. J. E. Marr, in writing of this outcrop, observes:—

'It seems highly improbable that the coal is truly interstratified with the marine limestones, and I consider that the most probable explanation of its occurrence is that the limestone has been thrust over the Coal Measures beneath, and that the coal has been squeezed up between two bedding-planes of the limestone.' (39, p. 352.)

Prof. P. F. Kendall, on the other hand, considers the coal contemporaneous with the limestone, and remarks:—

'The Carbonaceous division of the Bernician may represent a phase of which a mere trace is developed at Ingleton, in the form of an eroded fragment of a coal-seam with its underclay, that is intercalated in the Great Scar Limestone.' (37, p. 149.)

It is difficult to arrive at a definite conclusion regarding the origin of this patch of coal. Prof. Marr's contention that it is a fragment from the Ingleton Coalfield, brought into its present position by thrusting, appears to be supported by the undoubted evidence of thrusting in the quarry. As shown in the photograph (Pl. XIII, fig. 1), the base of the limestone above the coal is evidently a line of thrust; the surface of the shale is crushed, and the coal and shale die out northwards in the face of the quarry along this thrust-line. It is evident, then, that the line of thrust coincided nearly with the bedding, and that the softer beds of coal and shale have yielded more readily to the pressure than the limestone. As the coal thickens southwards and wedges out northwards, the upper beds above the thrust must have been carried from south to north. Again, this is the only exposure with which we are acquainted in West Yorkshire where a contemporaneous coal-seam has been found in limestones of Lower *Dibunophyllum* age, and it does seem a curious coincidence that the only section in which it is found occurs within a few hundred yards of the Ingleton Coalfield, and close to the South Craven Fault.

Over the West Yorkshire area in general the beds of the Lower *Dibunophyllum* Sub-zone appear to represent the clearest-water deposits of the whole Lower Carboniferous succession, and, although they may not have been deposited in really deep water, they seem to have been formed in an area far removed from the influence of land-derived detritus. It is difficult to see how even a local deposit of coal could be formed under these conditions. On the other hand, several partings of grey shale occur between the bedding-planes at higher levels in the quarry, which, judging by the iron-staining on the face below, evidently belong to the same type of mudstone as that associated with the coal; there is, however, no appearance of thrusting along these horizons, apart from a general tendency to movement along bedding-planes as the result of the formation of the anticlinal fold.

As already mentioned, the *Cyrtina-septosa* Band crops out in the floor of the quarry, but is found again at a higher level near the extreme southern end of the section, where a thrust making

a low angle with the horizon cuts across the bedding-planes of the limestones which here dip at about 25° southwards (Pl. XIII. fig. 1).

On the whole, for the reasons given above, and in view of general signs of movement in the district, we are inclined to think that Prof. Marr's view that the coal is a fragment of the neighbouring Coal Measures brought into its present position by earth-movements is the most satisfactory explanation of its presence in the limestone.

[During a meeting of the Yorkshire Geological Society in the Settle District, held in June 1922, we had the advantage of hearing Prof. P. F. Kendall explain his views on the spot. While admitting that the beds above the coal were thrust, he considered that the coal itself was due to contemporaneous deposition, and he thought that he could detect the presence of rootlets in the surface of the underlying limestone. Mr. E. E. L. Dixon, who was also present, made a careful examination of the surface of the limestone below the shale: he considered that it showed distinct traces of weathering and that the depressions on its surface were of the nature of potholes; he was further of the opinion that the shale filling the depressions appeared to have been deposited in its present position. He referred to similar pot-holes which had been noticed by Mr. C. Edmonds (15) in the limestone of the *Dibunophyllum* Zone in Cumberland, and also alluded to similar phenomena in Gower where a thin coal with underclay, first described by R. H. Tiddeman, showed rootlets intercalated among the same beds. He instanced a further example in the South-Western Province where the potholes occur beneath an unconformable covering of Millstone Grit. For these reasons he believed that the mudstones and coal in Meal Bank Quarry were part of the normal sequence, and were of D_1 age. As mentioned above, two more shale-bands occur higher in the face of the quarry, and the statements made in the above discussion recalled to us a similar shale-band which we had noticed near the summit of the old quarries beside the railway, about half a mile south-east of Ribblehead Station. On our revisiting the section after this meeting, it was found that the surface of the limestone below the mudstone was distinctly worn, and contained wide shallow depressions presenting an appearance which closely resembled that of the surface of the limestone below the coal in Meal Bank Quarry. The horizon of this exposure on the railway is some 56 or 60 feet above the *Cyrtina-septosa* Band, and may correspond to the upper shale-horizon in Meal Bank Quarry. It seems possible, therefore, that contemporaneous erosion has actually taken place at certain horizons in the D_1 limestone series of West Yorkshire, and that the shale and, therefore, possibly also the coal in Meal Bank Quarry are contemporaneous deposits.—*February, 1924.*]

The nodular bed and the *Cyrtina* Band reappear on the left bank of the Greta, and can be traced from the limekiln across Storrs Common until they disappear under the surface-deposits

near the boundary-wall at the eastern end of the Common. The nodular bed is here more compact than in the quarry, and is more in the nature of a pseudo-breccia, while the *Cyrtina* Band is more fossiliferous. On Storrs Common east of the main road, and above the *Cyrtina* Band, there is a continuous outcrop of limestone forming a thick series of beds which extends nearly to Storrs Hall, a horizontal distance of 220 yards. The beds dip at 20° south-south-westwards in that northern portion; but the dip increases to 30° where last seen near the South Craven Fault. If we take an average dip of 25°, this gives a total thickness for these beds of 280 feet. The beds appear to belong throughout to the D_1 subzone, and there is no trace of any beds belonging to the overlying D_2 horizon. About 75 feet above the *Cyrtina* Band mentioned above we find a layer rich in corals, also containing a few specimens of *Cyrtina*. Immediately beneath this bed there appears to be evidence of movement, shown by a smoothed surface cutting the bedding-planes at a low angle (Pl. XIII, fig. 2).

Immediately above the coral-bed comes another nodular bed, also containing rolled corals, and closely resembling the lower nodular bed of Meal Bank Quarry. Above this the beds are sparingly fossiliferous, until we reach a well-marked bedding-plane close to the summit of the series, which is crowded with *Cyrtina septosa* and other fossils characteristic of the *Cyrtina* Band. This band lies 250 feet above the lower *Cyrtina* Band which we have traced up from the limekiln. Thus there would appear to be 250 feet of limestone containing *C. septosa* on Storrs Common, although the average thickness of the beds between the richly fossiliferous *Cyrtina* Band and the base of D_2 at the southern end of Ingleborough and elsewhere in the district, is 100 feet or less; consequently, on Storrs Common the apparent thickness of the beds containing *C. septosa* is three times as great as the normal development elsewhere in the district. This unusual development of the upper beds of D_1 above the *Cyrtina* Band can only be explained, either by a very sudden and exceptional thickening of this portion of the sequence, or by a repetition of the beds due to faulting or thrusting.

The presence of a second nodular bed above the lower *Cyrtina* Band may be due to a return of similar conditions, and not necessarily to repetition of the same bed; but the presence of the upper *Cyrtina* Band, 250 feet above the lower, can hardly be explained in this way, and it is difficult to avoid the conclusion that the beds on Storrs Common are repeated by faulting or thrusting. No definite line of movement which would account for this repetition has been traced on Storrs Common, except the apparently insignificant plane of movement mentioned above (Pl. XIII, fig. 2); but evidence of movements in the district appears to be indicated by a well-developed cleavage in the limestone.

The upper *Cyrtina* Band on Storrs Common disappears under surface-deposits when traced south-eastwards to Fell Lane, but reappears farther south-east in the tramway-cutting at the winding-

shed on the right bank of Jenkin Beck. On the other side of the beck it is exposed in a small hillock, immediately below the point where a tributary enters from the north-east. Farther down stream in the steep wooded gorge there is an outcrop of the underlying nodular limestone of Meal Bank Quarry, which is shifted repeatedly by a series of small step-faults running parallel to the gorge, the downthrow of these faults being westwards. Below this the lower beds of D_1 can be traced in both banks of the stream dipping 35° south-south-eastwards, until they disappear against the South Craven Fault, where they are highly dolomitized. Returning up stream to the hillock on the left bank containing the *Cyrtina* Band, we find that the beds, which below this have been dipping consistently down stream, turn over and dip north-eastwards. Above the hillock the beck is seen to make two sharp turns before reaching the North Craven Fault. The section in this portion of the beck is of especial interest, as in a distance of less than 300 yards four important zonal horizons of the North-Western succession are brought into close proximity. At the North Craven Fault the Coniston Limestone, with the overlying beds of the *Michelinia* Zone, is brought against the Yoredale Beds on the south-west. By good luck the exact horizon of these Yoredale Beds can be definitely determined. They are exposed on the right bank of the stream at the corner where the beck takes a sharp turn north-westwards. The beds here consist of dark platy limestone containing *Productus latissimus* and *P. edelburgensis*, overlain by a thin band of cherty limestone containing *Orionastræa phillipsi*. This is evidently the *Orionastræa* Band which occurs in Mere Gill on the western flank of Ingleborough described above. It is possible, therefore, to estimate with considerable accuracy the throw of the North Craven Fault in Jenkin Beck. The average thickness of the beds between the *Michelinia* Zone and the *Girvanella* Band in Chapel-le-Dale is 540 feet; while the position of the *Orionastræa* Band in Mere Gill is 100 feet above the *Girvanella* Band, so that the throw of the North Craven Fault is approximately 640 feet. Below the corner where the *Orionastræa* Beds occur, the stream makes a sharp bend north-north-westwards. The left bank here rises into a steep cliff, near the summit of which is an outcrop of the *Girvanella* Band marking the base of D_2. Its position is indicated by a thin shaly layer, which has weathered back to form a ledge in the cliff. The beds here dip 10° north-eastwards, or towards the *Orionastræa* Band on the opposite bank. It is evident that the stream runs along a line of dislocation which has determined the sudden change in its course. This fault, which throws the beds up on the south-west, brings the *Girvanella* Band about 20 feet above the *Orionastræa* Band, and must therefore have a displacement of 120 feet. At the western corner of the cliff the *Girvanella* Band is separated from the *Cyrtina* Band of the hillock by a mass of dolomite. This evidently marks the position of another fault, which brings up the *Cyrtina* Beds

nearly on a level with the *Girvanella* Band. As the *Cyrtina* Band occurs normally some 80 feet below the *Girvanella* Band, this fault must throw up the beds some 60 feet or more on the south. The dolomite reappears in the opposite bank beyond the tributary which enters from the north-east, and here the limestone beside it is highly cleaved, the strike of the cleavage being west-north-westerly and the dip 55° north-eastwards. These subsidiary dislocations in the strip between the Craven Faults, which bring up lower beds in each case on the south-west, do not appear to be explicable by movement of the beds in connexion with the Craven Faults, as the downthrow of these faults is south-westwards in each case. It appears, then, that they are either overthrusts from the south-west which took place before the South Craven Fault came into existence, or are connected with dislocations of the South Craven Fault of the nature of tear-faults. This evidence of dislocations in the rocks between the Craven Faults in Jenkin Beck is suggestive in connexion with the thickening of the *Cyrtina* Beds on Storrs Common.

Between Jenkin Beck and Austwick the ground is much obscured by drift, but the *Nematophyllum minus* Beds and the *Cyrtina* Band can be traced at intervals. The Yoredale Beds, however, have been completely denuded here. The *Cyrtina* Band appears to be again repeated between Clapham and Austwick by a strike-fault or thrust. From Austwick to Settle the strip between the faults is occupied chiefly by beds of the Lower *Dibunophyllum* Sub-zone; but outliers of the Lower Yoredale rocks also occur. The district is traversed by a series of north-west and south-east faults which have been determined by mapping the outcrops of the *Cyrtina* Beds and the *Girvanella* Band. The Lower *Lonsdalia* Beds are well exposed in Blackrigg Quarry, and in an outlier, part of Common Scar, about 300 yards north-west of Brunton House. In Blackrigg Quarry the base of this series, seen in the cutting which forms the southern entrance to the quarry, contains a layer of *Stenophragma* sp. The lower portion of the main quarry has yielded the characteristic fauna of the Lower *Lonsdalia* Beds, and in addition well-developed examples of *Spirifer humerosus*, which is a rare form only met with elsewhere in the district at this horizon in Cow Gill, near Bordley, east of Settle. The shelf in the upper portion of the quarry contains examples of the concretionary fossiliferous nodules from this horizon in the district north of the faults. The beds are cut off on the north-west of the quarry by one of the north-west and south-east faults so common in this part of the district. This brings up the *Cyrtina* Band, which here exhibits a rich fossiliferous development. The repeated shifting of the outcrop of these beds as they are traced north-eastwards is shown on the accompanying map (Pl. XXI). The succession above the Lower *Lonsdalia* Beds consists of barren, thinly-bedded, crinoidal limestone; at the top of this traces of the Bryozoa Series, which forms an

important layer in the succession east of Settle, may be observed. The highest horizon in the Yoredale Beds seen in this district is the *Orionastræa* Band, which is exposed in a low escarpment facing south-westwards, about a third of a mile north-east of Brunton House and about the same distance south of Feizor hamlet. The band here contains an exceptionally large variety of *Orionastræa phillipsi*, together with *Lithostrotion junceum*, *Dibunophyllum* sp., and sponge-spicules. Chert occurs in the upper portion of the band, and the fossils are partly silicified. The lower portion of the limestone, as round Ingleborough, is dark and compact, and contains *Productus latissimus*, *P. edelburgensis*, *P. pugilis*, and *P. quadratus* (sp. nov. Muir-Wood MS.). Other species collected from this band include *Aulophyllum fungites*, *Favosites parasitica*, and *Productus sulcatus*. A shale is exposed in the low ground close by; but it is apparently faulted, and its exact position with regard to the *Orionastræa* Band is uncertain. The general character of that band here and the underlying *Productus-latissimus* Limestone is similar to the development on the north-western flank of Ingleborough, and it seems probable that the shale just mentioned represents the shale underlying the *P.-latissimus* Limestone in the district north of the fault.

To sum up: the district between the faults which lies north and west of Settle is entirely composed of rocks showing the normal development characteristic of the North-Western Province and of the area north of the faults in West Yorkshire, the only noteworthy modification being the more calcareous nature of the Yoredale Beds and the more prominent development of the *Orionastræa* Band.

District between the Faults—East of the Ribble.

This strip of country is, on the whole, the most interesting portion of the district under description, and certainly the most important in connexion with the marked lithological and faunal changes which take place in the neighbourhood of the Middle Craven Fault. It will be necessary, therefore, to describe the succession in some detail, and afterwards to compare it with the development in the district lying immediately south of the faults.

On the Geological Survey maps, the greater part of the area west of Lee Gate House (with the exception of Black Hill and the district immediately south of it) is coloured the same as the Great Scar Limestone of the Ingleborough district: that is to say, the succession up to the *Girvanella* Nodular Band at the base of D_2. The beds actually included, however, range up to the summit of the *Orionastræa* series, and in the eastern portion of the area near Bordley include even higher beds of D_3 age.

The base of the Carboniferous is nowhere actually seen, neither has the *Michelinia* Zone been identified, except at the two extremities of the district: namely, in the railway-cutting near Great Stainforth, and in the bed of the Wharfe opposite Kilnsey, north of the faults as already described. The Silurian floor is

stated by Davis & Lees (13, p. 38) to occur at the entrance to Gordale; while Mr. Cosmo Johns (33) suggests that the line of springs which occur at the foot of Settle Banks may indicate the position of an impervious barrier of pre-Carboniferous rocks. No exposure, however, of such rocks does actually occur, nor should we expect them here, as the springs issue at the 1150-foot contour, while the base of D_1 lies about the 1250-foot contour, leaving only some 100 to 120 feet for the whole of the *Productus* (S) and the *Michelinia* (C) beds, which between Settle and Langcliffe, a mile farther west, have a thickness of 300 feet or more.

(*a*) The succession between Settle and Malham.—As already mentioned, the age of the lowest beds exposed in the Ribble at Settle Bridge and at King's Mill (the Old Snuff Mill) is problematic; but they should represent the *Michelinia* Zone. The overlying beds, which crop out at intervals along the eastern slope of the Ribble valley between Settle and Langcliffe, consist of dark limestones, and represent the Gastropod Beds (S_1) of the North-Western Province. The overlying *Nematophyllum-minus* Beds (S_2) are well exposed at the top of Banks Lane, where they form a terraced outcrop dipping 10° north-north-westwards. They consist of dark-grey limestones, similar to the beds which form the lower portion of Horton and Coombe's Quarries north of the faults. They contain good specimens of the index-fossil, together with a large form of diphyphyllid *Lithostrotion*,[1] *Straparollus dionysii*, and a few other fossils. This exposure of the *N.-minus* Beds can be traced from Banks Nursery northwards to the neighbourhood of Langcliffe Quarry; but this horizon with its index-fossil has not been identified on the western bank of the Ribble. The beds appear to pass up normally into the overlying D_1 series under Blua Crags; but their relation to the beds east and south of Banks Nursery is obscure. The main escarpment forming Blua Crags, Warrendale Knotts, and Attermire Scar is separated from the ridge forming High Hills on the south, by an east-and-west fault, the 'Attermire Fault', which occupies the depression running from the southern end of Blua Crags eastwards to beyond Stockdale Farm, where it appears to join the Middle Craven Fault. At its western end this Attermire fault coincides generally with the footpath which leads from Banks Lane to the Rifle Butts, and on the south side of which, D_1 beds are seen dipping steeply northwards to the fault. Prof. J. E. Marr, who first called attention to this fault (which is not indicated on the Geological Survey map), suggested that it continued westwards past Banks Nursery, and crossed the Ribble between Settle and Langcliffe. This would be a reasonable expectation for anyone viewing the fault from the east; but the fault cannot be traced in the field beyond the neighbourhood of Banks Nursery, where the *Nematophyllum-minus* Beds appear to crop out uninterruptedly across its

[1] Compare *Diphyphyllum lateseptatum* var. *giganteum* Thomson.

supposed course (Pl. X). It must, therefore, either die out here, or turn north-north-westwards to Langcliffe, or south-south-westwards to Castlebergh, where a fault evidently occurs, skirting this limestone block on the south-east. The structure, indeed, of the strip of ground lying between the Attermire Fault and the Middle Craven Fault of the Geological Survey map is very complicated and puzzling, and it will be best to leave the detailed description of that area until later, confining our attention at present to the main outcrop lying north of the Attermire Fault.

Over the area east of Settle and Langcliffe the exact junction between S and D is difficult to determine, as the beds are extremely unfossiliferous, and the porcellanous layer which divides these zones elsewhere has not been definitely identified in the district between the faults. The line of junction shown on the map (Pl. XXI), therefore, only represents approximately the position of the base of D_1. The *Cyrtina-septosa* Band can be traced over most of the western portion of this district as far as Settle Scar, east of which even this horizon appears to be devoid of fossils in the neighbourhood of the Middle Craven Fault. The district is traversed by several north-west to south-east faults which have been determined by mapping the outcrop of the *Cyrtina* Band. The most important of these faults is that which runs from a little east of the Rifle Butts, past the foot of the Victoria Cave to Upper Winskill Farm, mentioned by Mr. Cosmo Johns (33). The downthrow here is westwards, repeating the outcrop of the *Cyrtina* Band, and giving rise to the escarpment of Langcliffe Scars and Attermire Scar.

An excellent exposure of the *Cyrtina* Band may be seen in Langcliffe Scar, in the face of an old quarry close to the gate on the road leading from Langcliffe to Cowside Farm. Over this area the band contains concretionary structures resembling algal nodules, and is associated with a fine-grained false-bedded layer, both of which are conspicuous on the weathered surfaces. Apart, however, from the *Cyrtina* Band, the D_1 beds are singularly unfossiliferous. Specimens of *Productus maximus* and large examples of *Euomphalus acutiformis* are, however, occasionally met with.

Above the *Cyrtina* Band the beds become darker and more crinoidal, and pass upwards into D_2. The base of the Lower *Lonsdalia* Beds is marked, as usual, by the *Girvanella* Nodular Band, which can be traced with the overlying Lower *Lonsdalia* Beds at intervals between Cowside Farm and Great Scar, north-east of Stockdale Farm. East of this the outcrop is interrupted by the Grizedales Fault, which here runs out against the Middle Craven Fault. The base of D_2 reappears at the surface farther east at Twin Bottom Scar, and can be traced hence in a northerly direction until it is faulted out by the north-west and south-east fault which runs along the foot of Long Scar.

Above the Lower *Lonsdalia* horizon the beds consist of thinly-bedded crinoidal limestone, for the greater part devoid of other fossils; but, towards the top of the series, silicified specimens of

Athyris lamellosa and *Spirifer bisulcatus* occur plentifully, together with a few cup-corals. The presence of *Athyris lamellosa* is characteristic of this horizon, and is of zonal value in the Settle district, as it is not met with at other levels. This horizon is also characterized by the occurrence of a thin layer rich in bryozoa, notably *Stenophragma* and *Dyscritella*. This layer is well seen in the cliff behind the old limekiln on Great Scar, and appears to mark a constant horizon. Its outcrop is indicated on the map (Pl. XXI) as it has been found useful in bringing out the structure of the district. These crinoidal beds lying between the Lower *Lonsdalia* horizon and the *Orionastræa* Band, which we may conveniently define as 'the Bryozoa Series', represent apparently the horizon of the Hardraw Shale in Wensleydale and the *Productus-pugilis* Beds on the north-western flank of Ingleborough and in Cam Beck. Although the Bryozoa Series as a whole is poor in fossils, there are one or two exposures where the fauna is peculiarly rich. The most important of these occurs near the head of the Stockdale Beck, 300 yards south-west of Twin Bottom Scar, and close to the Middle Craven Fault near the track leading from Stockdale Farm to Malham. Here a metalliferous vein was formerly exploited for lead- and zinc-ores, and fragments of copper carbonate are also still to be found in the old washings.

A section of the limestone is exposed in an excavation, now partly filled with water, and is conspicuous for the number of cup-corals weathered out along its face, (a similar development occurs on the right bank of Moor Close Gill in the Bordley district, to be described later); both exposures appear to lie at the same horizon: namely, a short distance below the summit of the Bryozoa Series. The list on p. 223 includes specimens from both of these localities.

This fauna, taken as a whole, is noteworthy. *Codaster acutus*, for instance, has not been met with in the North-Western Province; but it is recorded from Bowland by M'Coy. It occurs in considerable numbers at the lead-workings near Pikedaw, but we have only found two specimens in the Bordley district. Our collection also includes one specimen of *Codaster trilobatus*, which is recorded by M'Coy from Derbyshire. The presence of *Cyathaxonia rushiana* is also noteworthy: it has not been met with elsewhere in the Yorkshire district, and only in Great Rundal Beck in the Pennine area. The character of the deposit appears to point to shallow water, and most of the brachiopods are fragmentary, suggesting current-action or beach-formation. The fauna is more reminiscent of the 'knoll' development south of the faults than any bed met with elsewhere in the North-Western Province. At the same time, very few species are identical with those characteristic of the Malham reefs, and such characteristic knoll-reef forms as *Pugnax acuminatus*, *Spirifer striatus*, *Goniatites*, etc. are absent.

Fauna of the Bryozoa Series.

[1 = General outcrops between the Faults, east of Settle ; 2 = Old Lead-Workings, near Pikedaw ; 3 = Moor Close Gill, Bordley.]

	1	2	3
Girvanella sp.	...	+	...
Amplexus sp.	+	...	.
Caninia aff. *cornucopiæ* Michelin	...	+	...
Caninia sp., probably *cornucopiæ* Michelin	+	...	...
Caninia sp.	...	+	...
Cyathaxonia rushiana Vaughan	...	+	...
Cyathaxonia rushiana (freak)	...	+	...
Dibunophyllum sp.	+	.	
Michelinia (?) megastoma (M'Coy)	...	+	+
Michelinia tenuisepta Phillips	...	+	...
Zaphrentis aff. *enniskilleni* Edwards & Haime	+	+	...
Zaphrentis omaliusi Edwards & Haime	...	...	+
Zaphrentis sp. nov.	...	+	...
Zaphrentis sp. nov. 2 (also from Gauber High Pasture)	...	...	+
Zaphrentis spp.	+	...	+
Codaster acutus (M'Coy)	...	+	+
Codaster trilobatus (M'Coy)	...	+	...
Athyris globularis Phillips	...	...	+
Athyris planosulcata (Phillips)	...	...	+
Athyris sp.	...	...	+
Camarophoria crumena Martin	+	...	...
Chonetes buchiana L. G. de Koninck	...	...	+
Chonetes, probably *comoides* Sowerby	+	...	...
Leptæna analoga (Phillips)	+	...	.
Martinia glabra (Martin)	...	+	+
'*Orthotetes*'	..	...	+
Productus antiquatus Sowerby	+	...	...
Productus edelburgensis Phillips	...	+	...
Productus hemisphericus Sowerby	...	+	...
Productus longispinus Sowerby	+	...	+
Productus margaritaceus Phillips	+	+	+
Productus quadratus Muir-Wood (MS.)	..	+	...
Productus semireticulatus Martin & Davidson	+	...	...
Productus sulcatus Sowerby	+	+	...
Productus tessellatus L. G. de Koninck	...	+	+
Productus tissingtonensis Sibly	+	+	+

	1	2	3
Productus undatus Defrance	...	...	+
Productus spp.		+	
Proboscidiella nystiana L. G. de Koninck	...	..	+
Avonia semicostata Muir-Wood (MS.)		+	..
Avonia youngiana (Davidson)	+	...	+
Pustula keyserlingiana (L. G. de Koninck)		+	..
Pustula rugata (Phillips)	...	+	..
Pustula punctata (Martin)	+	.	...
Pustula magnituberculata Muir-Wood (MS.)	+	.	..
Pugnax pleurodon (Phillips)	...	..	+
Pugnax pugnus (Martin)	+	...	+
Reticularia (?) lineata (Martin)	+	.	
Schizophoria resupinata (one specimen only from each locality)	+	+	+
Seminula ambigua (Sowerby)	...	...	+
Spirifer bisulcatus Sowerby	+	+	+
Spirifer (?) convolutus var. *rhomboideus* Phillips	.	+	
Spirifer duplicicostus Phillips	...	+	
Spirifer (Brachythyris) ovalis Phillips	.	+	+
Spiriferina octoplicata Sowerby	..	+	..
Tylothyris laminosa (M'Coy)	+	+	.
Tylothyris subconica (Martin)	..	+	+
Dyscritella sp.	+	...	..
Retepora sp.	...	+	..
Fenestella sp.		+	
Leioclema sp.	+	.	.
Stenophragma sp. Munro = *Tabulipora* section B of Lee	+	+	...
Stenopora sp.	...	+	..
Luciella squamula (Phillips)	...	+	..
Naticopsis sp.		+	..
Nautilus sp.	...	+	..
Orthoceras sp.	...	+	+
Phillipsia seminifera (Phillips)	...	+	..
Trilobite-fragments	+	+	+

The Bryozoa Series on the high ground round Back Scar and Outside is succeeded by a thin cherty limestone, containing silicified specimens of *Lonsdalia floriformis*, *Alveolites*, and other fossils. This bed forms the dip-slope on Back Scar and in Gorbeck on the north-east, where it is shifted by the series of north-north-westerly faults which occur between Back Scar and Outside. It is well exposed at the western end of Great Scar near the sheep-fold (Pl. XV, fig. 2) and has been utilized for supplying material

for building the parish boundary-wall, which runs east and west across Clattering Sike, where many beautiful specimens of *Lonsdalia* may be seen. This cherty *Lonsdalia* Bed is again seen on the western face of Haw Knabs, immediately south-east of Black Hill, where it is brought to the surface on the upthrow side of an important north-west and south-east fault. Above the cherty limestone at the western end of Great Scar occurs a massive lenticular layer of limestone, composed entirely of crinoid débris. The bedding here is of interest, for, whereas the cherty *Lonsdalia* Bed shows a general synclinal structure, the bedding of the overlying crinoid lenticle is horizontal or even anticlinal in structure (Pl. XV, fig. 2). At first sight, this gives the impression of an unconformity at this horizon, as if the crinoid-bed had been deposited on the folded surface of the syncline. It is more probable, however, that the phenomenon is the result of pressure acting subsequently to the deposition of both beds, and that the massive crinoidal layer has resisted compression, causing the more yielding beds below to fold round it. It is, therefore, an interesting example of how knoll-structure may arise, and be subsequently emphasized by earth-movements. A similar crinoidal layer also occurs above the chert-bed on Haw Knabs. The higher Yoredale Beds are not well exposed, as the area is much drift-covered. The dip-slope evidently represents the summit of the Bryozoa Series, and some of the exposures in pot-holes have yielded *Productus pugilis*. In Clattering Sike, the stream has cut down through a bed of shale a few feet thick, the upper calcareous portion of which contains abundant specimens of *Productus latissimus*. The bed is also interesting, on account of the numerous specimens of small Zaphrentids which it contains (*Zaphrentis constricta*, *Z. costata*, *Z. densa*, and *Z. enniskilleni*). The overlying limestone, which is not well exposed, evidently represents the *Orionastræa* Band, and several large fragments of *O. phillipsi* were found washed out of this bed; while large specimens can be seen in the wall close by. North of this the beds are much obscured by drift, and the structure is difficult to determine. The few isolated exposures of limestone that do occur afford no evidence of their exact position in the sequence. The outcrop of grit on Black Hill is coloured on the Geological Survey map as Millstone Grit. It is separated from the beds of Haw Knabs by a fault, and there appears to be no representative of the Main Limestone in the neighbourhood. It is possible that it represents a grit in the higher portion of the Yoredale Beds.

(*b*) The district between Malham and Bordley.—The area between the faults north of Malham, stretching from Pikedaw Hill to Great Knott, is almost entirely composed of rocks belonging to the Lower *Dibunophyllum* Sub-zone. The *Cyrtina-septosa* Band can be traced over the greater portion of the district, but is interrupted in places by small faults which have the usual north-westerly or north-north-westerly trend. The most important of

these is that which runs between Dean Scar and Ing Scar, bringing the *Girvanella* Band against the *Cyrtina* Band at Lang Scar with a throw of 80–100 feet down to the south-west. The other faults are little more than cracks or master-joints, but their existence has an important influence in determining the surface-features of the district. Thus, Trowgate and the depressions on each side of Abbot Hills coincide with three of these dislocations; while Gordale, although it shows but a slight displacement of the *Cyrtina* Band which crops out round the edge of the gorge, has doubtless been determined by a crack with a similar north-north-westerly trend.

The lower portions of the scars at Malham Cove and at the entrance of Gordale should include the horizon of the *Nematophyllum-minus* Beds, as the base of the cliff in each case lies some 400 feet below the *Cyrtina* Band, and the average thickness of D_1 below that band, wherever it has been measured elsewhere, is only 180 to 200 feet. The beds here are, however, almost totally devoid of fossils, and no definite evidence of their age has been obtained.

About a mile east-south-east of Pikedaw Hill, and immediately north of the Middle Craven Fault, occurs a bed of limestone-conglomerate containing pebbles measuring up to 3 inches in diameter, and a similar bed is also found farther east on Great Knott. These two patches of conglomerate do not, however, belong to the same horizon: for, while the outcrop near Pikedaw lies some distance below the *Cyrtina* Band, the bed at Great Knott occurs above this band not far below the base of D_2. These limestone-conglomerates are very similar in character to those which occur below Middle High Hill and Halsteads Knoll east of Settle. The bed at Great Knott contains a few bipyramidal quartz-crystals, which are apparently confined to the pebbles (Pl. XIX, fig. 5 *a*). These patches of conglomerate appear to be a contemporaneous deposit, and not a crush-conglomerate, as their position near the Middle Craven Fault might suggest.

No beds of D_2 age have been identified north of Malham Lings. The highest beds, however, near the North Craven Fault on Dean Moor and Torlery Edge contain a *Productus* Band which must lie very nearly, if not actually, at the base of D_2. This band is a thin gritty limestone, crowded with rolled Producti, including a small form of *P. striatus*.

Between Gordale and Bordley Beck the area may roughly be divided into three portions. In the west and north-west the surface is still occupied by beds belonging to the Lower *Dibunophyllum* Sub-zone; while the central and north-eastern portion is composed of the Yoredale Beds, which here include the cherty *Orionastræa* Band, together with 50 feet of the overlying limestone. The southern portion, however, for a third of a mile north of the Middle Craven Fault, is not composed of rocks belonging to the Northern Succession, but is occupied by a mass of Bowland Shale belonging to the succession which is elsewhere characteristic

of the country south of the faults. The stratigraphical relation of this mass of shale to the northern series is obviously a discordant one, as several different horizons of the Northern Succession abut against its western and northern margins. The exact relationship of the two series will be dealt with later, when other patches of rock of southern facies occurring north of the Middle Craven Fault are discussed.

The Lower Yoredale Beds occupying the central and north-eastern portion of this area show a development similar to those which represent this portion of the succession north-east of Malham, but they differ in certain particulars. The whole succession is composed of limestone, and there is no true shale developed beyond the thin shaly partings usually present in the Lower *Lonsdalia* Beds. The *Girvanella* Band, at the base, is well exposed in Cow Gill and in its continuation in Heber Beck; while the Lower *Lonsdalia* Beds with *Productus giganteus* can be examined at the waterfall in Cow Gill, where they are highly fossiliferous. Below the waterfall the succession is interrupted by a small north-westerly fault which runs diagonally across the beck, and brings down the higher beds on the north-east. The Lower *Lonsdalia* Beds at the fall are characterized by an abundance of a large form of *Reticularia lineata*, while the shaly partings contain the nodular concretions described from this horizon on Ingleborough, and enclose the same species of *Zaphrentis*. This bed also contains a new genus of coral, which has been identified by Mr. R. G. Carruthers as similar to a form that he has found at Bundoran (Donegal), but has not yet described and named. We append a list of the fauna from the Lower *Lonsdalia* Beds, between the faults east of Settle:—

Girvanella sp.

Endothyra sp.
Valvulina sp.

Amplexus sp.
Caninia cylindrica Scouler.
Caninia sp.
Dibunophyllum splendens Thomson; one specimen.
Lithostrotion maccoyanum Edwards & Haime.
Lonsdalia floriformis (Fleming).
Zaphrentis sp. nov. 1.
Zaphrentis aff. *enniskilleni* Edwards & Haime.

Chonetes sp.
Dielasma hastatum (Sowerby).
Martinia glabra (Martin).
Productus cf. *concinnus* Sowerby.
Productus giganteus Martin.
Productus latissimus Sowerby.
Productus near *lobatus* Sowerby.
Productus pugilis Phillips; early mutation, plentiful.
Productus sulcatus Sowerby.
Buxtonia scabricula (Martin).
Pustula punctata (Martin).
Reticularia lineata (Martin); large form, very abundant.
Schizophoria resupinata (Martin).
Spirifer bisulcatus Sowerby.
Spirifer humerosus Phillips.
Tylothyris laminosa (M'Coy).

Pinna flabelliformis Martin.

Trilobite-fragments.

The Bryozoa Series, which overlies the Lower *Lonsdalia* Beds, is here somewhat reduced in thickness; but the beds are well exposed immediately east of the waterfall in Moor Close Gill,

where they are highly fossiliferous. The development here is similar to that found at the old lead-workings near Pikedaw Hill described above, where a list of species collected from both localities is included (p. 223). Specimens of *Codaster acutus*, however, are rare at Moor Close Gill; but the fauna shows the same approach to the knoll-reef type of development as at Pikedaw Hill. *Michelinia megastoma* and *Tylothyris subconica*, *Productus tissingtonensis*, *P. margaritaceus*, and *P. tessellatus* occur in both localities, while young forms of *Martinia glabra* are common.

The beds, which consist of crinoidal limestone, are somewhat recrystallized and impregnated with dolomite, apparently owing to their proximity to the small fault which crosses Cow Gill and Moor Close Gill mentioned above. The overlying *Orionastræa* Band crops out in a small mound on the left bank of Moor Close Gill near the waterfall, and is underlain (as usual) by a compact dark limestone yielding *Productus latissimus* and *P. edelburgensis*. A better exposure of the band, however, occurs on the right bank of Cow Gill a quarter of a mile north of New Houses, where it crops out near the top of the cliff. Here we find the best development of the *Orionastræa* Band in the district. The index-species forms lenticular masses interbedded with reefs of the fine variety of *Lithostrotion junceum* commonly found at this horizon elsewhere. The band contains abundant lenticles of chert, and the corals are partly silicified. The fauna includes examples of *Pemmatites* (Pl. XVIII, fig. 2) and anchoring spines of *Hyalostelia*, identical with those recorded above from the Lamellibranch Bed on Ingleborough. The *Orionastræa* Band is overlain by about 50 feet of crinoidal limestone, which is exposed at the top of the cliff below New Houses Farm. The upper portion of the section is fossiliferous, and contains *Lonsdalia floriformis crassiconus*, and the following fauna, some of the specimens being replaced by beekite:—

Dibunophyllum sp. } both very weathered specimens
Lophophyllum sp. }
Productus edelburgensis Phillips.
Productus longispinus Sowerby.
Productus pugilis var. Phillips.
Productus quadratus Muir-Wood (MS.).
Buxtonia scabricula Martin.
Overtonia fimbriata J. de C. Sowerby.
Pustula spinulosa Sowerby.

Fish-tooth.

These are the highest beds of the Northern Succession exposed in the district between Malham and Bordley. On the whole, the succession, compared with the western portion of the district, is characterized by the more pronounced calcareous development of the higher beds and the total absence of true shale. The district is traversed by two north-west and south-east faults in addition to that described in Cow Gill. These appear to let down a narrow tract of ground between them, forming a small rift-valley immediately east of Lee Gate House.

IV. The District South of the Faults.

In the district immediately south-west of the South Craven Fault, between Ingleton and Settle, the Carboniferous rocks exposed at the surface consist entirely of Millstone Grit and Coal Measures, and there are no exposures of the Lower Carboniferous until we reach Green Pike near Dale House. East of Settle, however, between Settle and the valley of the Wharfe, are three areas where the beds underlying the Millstone Grit appear at the surface abutting against the southern margin of the Middle Craven Fault. The first of these occurs in the Scaleber area near Settle, the second in the Malham area, and the third in the Knoll area at Cracoe. In all these places typical knoll-reef limestones occur, succeeded apparently by Bowland Shales. It is not the purpose of the present paper to describe in detail the geology of the country lying south of the faults. It is necessary, however, to give some account of the succession in the Scaleber and Malham areas, in order that a comparison may be instituted between the southern facies and the succession established north of the Middle Craven Fault. These areas are not included in the description of the Craven Lowlands given by Dr. A. Wilmore, and, as already stated, no memoir has been published dealing with Sheet 60 of the Geological Survey map, which includes these areas.

(1) The Scaleber Area.

Immediately east of Settle, the South Craven Fault is joined by the Middle Craven Fault, which runs eastwards by Malham to the neighbourhood of Threshfield; while the South Craven Fault trends south-eastwards in the direction of Skipton. It is in the angle between these two faults that the limestones and shales appear from beneath the grits in the Scaleber area. The country is partly covered with drift, which appears to have given rise to a small glacial lake at Halsteads. The overflow from this lake has cut a gorge through the knoll-reef limestone in the lower portion of Stockdale Beck, and has also excavated the gorge of Scaleber Beck below Scaleber Force, thus exposing a continuous section between the Middle Craven Fault and the Skipton branch of the South Craven Fault.

The limestones in Stockdale gorge are partly dolomitized and impregnated with silica, while a north-to-south fault brings on the Bowland Shales east of the gorge, so that the true thickness of the knoll-limestones is difficult to ascertain. The general succession in this area appears to be as follows:—

Kinderscout (?) Grit.
Pendle Grit, with sandy shales.
Bowland Shales.
Knoll-Limestone.
Limestone and chert of Scaleber Quarry, overlain by dolomite.
Black Limestone, with shaly partings, of Scaleber Force.

The lowest beds exposed are the dark limestones of Scaleber Beck, seen in the waterfall and in the gorge below. The base is not reached, as the beds are faulted against the grits by the Skipton branch of the South Craven Fault. Altogether, about 120 feet of black limestones with shaly partings are exposed in Scaleber Beck. The fauna is scanty, but the following species have been collected from this series:—

Diphyphyllum sp.
Lithostrotion irregulare (Phillips).
Zaphrentis sp. (*enniskilleni* gens).

Seminula ambigua (Sowerby).
Chonetes hardrensis Phillips.
Chonetes papilionacea Phillips.
Derbya gigantea Thomas.
Leptæna analoga Phillips.
'*Orthotetes*' sp.
Productus concinnus Sowerby.
Productus corrugatus M'Coy.
Productus ϕ Sibly.
Pustula aculeata (Martin).
Pustula elegans (M'Coy).
Pustula punctata (Martin).
Reticularia lineata (Martin).
Schizophoria resupinata (Martin); large form.
Spirifer bisulcatus Sowerby.
Brachythyris ovalis (Phillips).

Modiola sp.
Platyschisma glabrata Phillips.
Straparollus sp.

Griffithides sp.
Phillipsia sp.

This fauna suggests a high horizon in D, *Productus concinnus* and *P.* ϕ being typical D_2 forms in Derbyshire; while *Pustula aculeata*, *P. elegans*, and *Brachythyris ovalis* are characteristic forms in the Cracoe Reefs. On the whole, the fauna suggests a D_2 horizon.

Immediately overlying this series we find 25 feet of dark limestone with shaly partings, containing chert-nodules, exposed in Scaleber Quarry north of the road. The beds here are much more fossiliferous than the underlying series, and the following species have been collected from the beds in this quarry:—

Caninia cylindrica Scouler.
Caninia sp.
Lithostrotion affine (Fleming).
Lithostrotion arachnoideum (M'Coy).
Lithostrotion irregulare (Phillips).
Lithostrotion portlocki (Bronn).
Michelinia sp.
Syringopora reticulata Goldfuss.

Athyris sp.
Chonetes compressa Sibly.
Chonetes papilionacea Phillips.
Martinia glabra (Martin).
Orbiculoidea nitida (Phillips).
Productus aff. *concinnus* Sowerby.
Productus spp.
Buxtonia scabricula (Martin); a typical D_2 form.
Pustula elegans (M'Coy).
Pustula punctata (Martin).
Schizophoria resupinata (Martin).
'*Orthotetes*' sp.

Edmondia sp.
Straparollus dionysii (Montfaucon).

Vestinautilus sp.

This assemblage appears to denote a D_2 to D_3 horizon. *Lithostrotion affine* is recorded from Castleton in Derbyshire, while the large form of *Schizophoria resupinata* appears to be identical with the form which occurs above the Lower *Lonsdalia* Beds at Sellet Mill near Kirkby Lonsdale, and Gleaston in Furness. The most important feature, however, is the occurrence of *Litho-*

strotion arachnoideum in considerable abundance. This coral has not been met with in the North-Western Province; but Mr. D. Parkinson informs us that he has recently found it to be not uncommon at the base of the Pendleside Limestone of the Clitheroe region.

The beds in the quarry show a slight anticlinal structure; the general dip, however, is north-north-westwards. About 60 yards north of the quarry and west of the gorge dolomite sets in, and still farther north most of the hillside between the road and the beck is composed of this material. Farther north again, knoll-reef limestone comes on, and also shows signs of dolomitization at its southern margin. This knoll-limestone culminates at the 1100-foot contour, and extends eastwards across Stockdale gorge and northwards to the Middle Craven Fault. On the eastern bank of the gorge the beds are apparently shifted to the north by a small fault, so that the black limestone of Scaleber Quarry forms a low cliff dipping 15° north-north-westwards and extending a considerable distance up the gorge. These beds are much altered and silicified, and contain local patches of dolomite. They terminate at the northern end against a patch of Bowland Shale which occupies a slight depression on the left bank, and are succeeded farther north by knoll-reef limestone, the beds being cleaved and dolomitized at the northern end of the gorge as they approach the Middle Craven Fault. The patch of Bowland Shale occupying the left bank just mentioned is somewhat difficult to account for; it may be brought in by a continuation of the fault which crosses Black Gill Beck at School Share, otherwise it might be interpreted as due to overlap of the Bowland Shales.

The fauna of the knoll-limestones closely resembles that of the Cracoe knolls, the fossils being distributed somewhat sporadically, certain species occurring in patches. This is markedly the case with the goniatites, which are specially abundant near the centre of the exposure on each side of the gorge. The collection of fossils presented by the late Mr. Burrow to the Sedgwick Museum, Cambridge, was probably obtained for the greater part from this knoll-reef limestone, and a list of species is given by McKenny Hughes in his paper on Ingleborough (30). A few of the more important species that we have collected from the reef-limestone here are enumerated in the table on pp. 239–42.

The main mass of Bowland Shale crops out a little to the east of the gorge, and, according to the Geological Survey map, is brought in by a north-and-south fault. This must certainly be the case, unless we postulate an overlap of the Bowland Shales in this district. The country is a good deal obscured by drift; but a few outcrops of Bowland Shale occur north of Black Gill Lane. The best section, however, is seen in Black Gill Beck, immediately south of the lane. In the lower part of this beck the shales are much disturbed in the neighbourhood of the eastern branch of the Settle-Skipton Fault, while farther up the stream a small fault is seen in the cliff on the left bank. At the head of

the beck, where it is crossed by the lane, the Bowland Shales are overlain by the Pendle Grit-with-Sandy Shales of the Geological Survey nomenclature. The Bowland Shales contain occasional 'bullions'; but both the nodules and the shales in the beck section are almost devoid of fossils, except for a few badly preserved specimens of *Posidonomya membranacea.* One nodule, however, collected from an outcrop of shale north of the lane, contained numerous specimens of *Glyphioceras pseudo-bilingue.* The chief interest of the section in Black Gill Beck is the presence of a shattered limestone which crops out in the cliff on the left bank, close to the fault mentioned above, and about a quarter of a mile south-east of Scaleber Bridge. This limestone is highly fossiliferous, and one of the more compact layers is crowded with concentric nodules, averaging about an inch in diameter, well seen on the weathered surfaces. Under the microscope these nodules are found to contain abundant cell-threads of *Girvanella* of two sizes, which resemble very closely the structures in the *Girvanella* Band that everywhere forms the base of D_2 in the succession north of the faults.

The fossils collected from this limestone include the following forms:—

Alveolites capillaris (Phillips).
Caninia sp.
Dibunophyllum sp.
Lithostrotion junceum (Fleming).
Lithostrotion maccoyanum Edwards & Haime.
Lithostrotion portlocki (Bronn).
Orionastræa ensifer (Edwards & Haime).
Zaphrentis densa Carruthers.
Zaphrentis sp.

Productus cf. *edelburgensis* Phillips.
Productus giganteus Martin.
Spirifer bisulcatus Sowerby.
Spirifer duplicicostus Phillips.

Bellerophon sp.

The outstanding feature of this fauna is the occurrence of *Orionastræa ensifer.* This species is plentiful in the Bristol district and in North Wales in D_2, but has not hitherto been recorded from Yorkshire. It is so far unrecorded from Derbyshire, Westmorland, and Scotland, but has recently been collected by Mr. Charles Edmonds from the fourth limestone (D_2) of Egremont, West Cumberland (15). So far as we are aware, it has not been found to occur in the normal southern development in the district south of the faults. The rest of the fauna, notably *Lithostrotion junceum*, *Productus giganteus*, and *Zaphrentis densa*, consists of typical species from D_2 of the North-Western Province facies north of the faults. The presence of *Girvanella* nodules is interesting, as they are characteristic of the base of D_2, and occur also in the Lower *Lonsdalia* Beds above. They have not hitherto been recorded from the normal succession south of the faults. This exposure in Black Gill Beck is the only clear section, south of the Middle Craven Fault in the Scaleber area, where a fossiliferous limestone has been found apparently incorporated in the Bowland Shales (39, p. 346, fig. 12). The limestone is much disturbed and ironstained, and

some of the blocks are partly isolated in the shale. The edges of the blocks are often rounded, and present a nodular appearance; and it is difficult to trace a definite succession in the deposit. The rock, as a whole, has a curious exotic look, resembling a fragment out of place. Its occurrence close to a small fault might have caused this appearance of shattering; but there is no sign of the limestone on the opposite bank, or elsewhere in the beck. The possibility of glacial transportation occurred to us, but was rejected. In any case this deposit, apparently in the Bowland Shales, presents a problem which cannot be satisfactorily solved until the detailed succession in the rocks farther south has been definitely established. Its appearance is not incompatible with the view that it represents an extension of the Yoredale Beds south of the Middle Craven Fault, over which Bowland Shales have been thrust before the Middle Craven Fault came into existence.

Another important exposure of limestone south of the faults occurs on High and Low South Bank, on the south side of Stockdale, opposite the farm. It forms a dip-slope, about a quarter of a square mile in extent, and is surrounded and overlain on three sides by Bowland Shales. The western portion, on Low South Bank, forms a small U-shaped outcrop about 300 yards wide at the base of the U, bounded on the east by the fault mentioned above, which coincides generally with the line of the wall. This portion consists of dark-grey limestone which, though somewhat altered and traversed by small calcite-veins, is fairly fossiliferous. The north-western extremity of the U is highly crinoidal, and resembles the fossiliferous Bryozoa Series near Bordley, north of the Middle Craven Fault. These beds include a layer containing crushed *Productus* and a specimen or two of *Dibunophyllum*.

Farther up the hill, near the base of the U, higher beds are exposed, which contain a reef of *Orionastræa phillipsi* associated with *Productus pugilis*, *P. edelburgensis*, and *Lithostrotion junceum*. This fauna is identical with that which occurs north of the Middle Craven Fault, both at Clattering Sike and in the Bordley district, and again round Ingleborough, the horizon represented being the *Orionastræa* Band and the underlying *Productus-pugilis* Beds. The presence of this exposure of limestone belonging to the North-Western Province facies on Low South Bank is of especial interest, proving, as it apparently does, that there is an extension of the northern facies beneath the Bowland Shales on the south side of the Middle Craven Fault. The limestone on Low South Bank, taken in conjunction with the section in Black Gill Beck previously described, shows clearly that the relation of the Bowland Shale to the underlying limestones is not a normal one, the horizon of the limestone under the shale in Black Gill Beck being apparently low D_2 and that on High South Bank being the base of D_3. The relation may suggest an

overlap of the Bowland Shales, but both sections may equally well be explained by movement of the shales over the limestone.

The relation of the limestone to the Bowland Shales on Low South Bank is not clear: there appears to be a fault or crush along the western limb of the U, as the limestone rises here above the level of the shales, although the dip is northward. A section showing Bowland Shales in contact with limestone is seen in a pot-hole, close to the wall on the 1450-foot contour at the south-eastern margin; but the relation of the two is difficult to determine, as the surface of the limestone has undergone solution, and the shales appear to have slipped. In the eastern or larger area on High South Bank, east of the fault, the limestone is much altered by impregnations of dolomite and silica: so much so, that over a large area hardly any unaltered limestone remains, except as kernels incorporated in the altered rock.

On the south-eastern margin, near the parish boundary-wall, about the 1550-foot contour, white porcellanous limestone resembling knoll-reef limestone is seen, apparently overlain by Bowland Shale. The exact relationship is obscure, and the shale may be crushed or faulted against the limestone. It appears, then, that the limestone of Low South Bank belongs to the northern succession; while the porcellanous limestone of High South Bank more nearly resembles the knoll-reef type of deposit. The two limestones are separated by the north-north-westerly fault; but the general relationship is obscured by the high degree of alteration which the limestone on the east has undergone.

The section might be interpreted as showing a passage from the northern succession to knoll-reef limestone of the southern type; but, if so, the passage takes place at the horizon of the *Orionastræa* Band, whereas on High Hill, if we postulate a passage there, it must be on the horizon of D_1. The presence of this extensive area of altered rock on High South Bank does not seem to be connected with the Middle Craven Fault, as the rock near this fault shows little alteration where it can be examined in the beck below, but seems much more in the nature of mineralization due to horizontal movement or thrusting, and in this respect resembles the massive dolomite above Scaleber Quarry.

(2) The Malham Area.

In this area the rocks immediately south of the Middle Craven Fault show a development similar to that in the Scaleber district, and the succession again has an entirely different facies from that of the North-Western Province; but the Middle Craven Fault here forms a sharp boundary between the two types.

The knoll-limestone is well exposed on Cawden and on Wedber Brow, where the beds exhibit marked quaquaversal dips. The present form of these domes appears to be due, at all events in part, to earth-movements. Much of the limestone is well bedded, and almost devoid of macroscopic fossils other than crinoid débris.

This is clearly seen on the southern flank of Cawden, where the beds dip steeply south-eastwards, and there is no sign here of the shelly accumulations so frequently invoked in connexion with the origin of these knolls. Again, on the northern slope of Cawden, the prevalent northward dip has evidently been influenced by proximity to the Middle Craven Fault. The fauna of these knolls is, in general, similar to that of the Cracoe knolls, and shows the same patchy distribution; a list of the typical species is embodied in the table on pp. 239–42. The fauna is again characterized by the presence of goniatites, *Glyphioceras crenistria* being especially abundant on Wedber Brow. Malham village is built on this knoll-limestone, which also extends some distance west of it. The limestone is overlain by Bowland Shale, which dips off it on the east, south, and west. Good sections in the shales are seen in Hanlith Gill and its tributaries, but here the beds have yielded no fossils. In Cow Close Sike however, they contain *Posidoniella lævis*, while some 'bullions' near the base are crowded with young specimens of *Glyphioceras pseudo-bilingue*. Between Wedber and Cow Close Sike the shales lie in a synclinal fold, so that west of Granny Gill the knoll-reef limestone reappears from under them on the left bank of the Aire, below Black Hole footbridge. The fauna here is similar to that of Wedber, and includes *Glyphioceras crenistria*. Farther south the limestone occupies the high ground above the 875-foot contour between Ingham House Laithe and Bark Laithe. The outcrop near Bark Laithe is of interest, as it contains an unusual development of bryozoa, notably *Hemitrypa* sp. (which forms reef-like layers several inches thick), and *Amplexus coralloides* is locally abundant. The beds immediately underlying the knoll-reef limestones consist of well-bedded earthy limestones with thin shaly partings, and contain abundant layers of chert. These beds, although thicker, appear to occupy a position similar to that of the cherty limestone in Scaleber Quarry; but, in the district south of Malham, they are singularly devoid of fossils, and exhibit a considerable amount of folding and disturbance. They are well exposed in the old quarries near Hellen Stead, where they dip 70° northwards, and also on Haw Hill, east of Hanlith Hall, where they are pinched into a sharp synclinal fold (Pl. XV, fig. 1). They can be seen dipping under knoll-reef limestone on the left bank of the Aire, opposite Scalegill Mill.

Similar beds, along the same line of strike, appear west of the river near New Close Barn, half a mile north of Kirkby Malham, where they are seen dipping 80° northwards, but turn up again to form a synclinal fold before reaching Pikedaw Barn. These chert-bearing beds are underlain by dark earthy shales with limestones, but devoid of chert. They crop out about a mile south of Hanlith Bridge, though a better exposure is seen west of the Aire in Kirkby Malham Beck, where some of the layers are fairly fossiliferous and contain Producti, notably *P. pugilis*,

P. margaritaceus, and *Pustula pustulosa*, together with *Caninia* sp. and other badly-preserved corals. These rocks resemble the beds of Scaleber gorge, and appear to occupy a similar position in the series. The occurrence of *Productus pugilis* in these beds is interesting, as this species is limited to a definite horizon near the summit of D_2, in the North-Western Province. The succession in the Malham district, therefore, so far resembles the development at Scaleber, and is in marked contrast throughout with the development in the North-Western Province.

South of Kirkby Malham Beck, grey limestones of a more massive character rise from beneath the shales with limestone. They crop out on Thornber and Tinderly Hills, and appear at intervals through the drift between Dikelands Farm and Holme (Ormsgill of the 6-inch map). Good fossiliferous exposures occur in old quarries at Airton Green Rock, and near the lime-kiln on Tinderly Hill, east of Scosthrop Lane. Here they contain abundant specimens of a large form of *Chonetes* sp. nov., reef-like masses of *Syringopora reticulata*, together with plentiful young forms of *Daviesiella llangollensis*, impregnated with secondary quartz-crystals. The last-named species occurs abundantly at the base of D_1 in the Kirkby Stephen area, and is generally considered to occupy a similar horizon, or slightly lower, in the Llangollen district and Anglesey. It has not been found in the Ingleborough district, but one full-grown example was collected by us from the road-quarry in the Hardraw Scar Limestone, south of Gale village, Wensleydale. On the whole, then, these limestones underlying the shales-with-limestones may be provisionally assigned to an horizon about S_2–D_1.

V. The Occurrence of Rocks of Southern Facies between the North and the Middle Craven Faults.

Although, as shown above, the strip of country lying between the faults belongs essentially to the North-Western Province succession, it also contains certain patches of rock of markedly southern facies. These patches are found in two places: namely (1) immediately east of Settle, and (2) about a mile east of Gordale, in the neighbourhood of Bordley. In the first locality we find a typical development of 'knoll-reef' limestone with its characteristic fauna; while in the second an isolated outlier of the Bowland Shale occupies a considerable area between the faults. Both these exposures lie close against the northern margin of the Middle Craven Fault. It is evident, therefore, that this fault does not everywhere form the boundary between the northern and the southern facies, as supposed by R. H. Tiddeman. The fact that patches of these rocks occur between the faults raises problems of sufficient importance to warrant their description in some detail.

(1) The High Hills District: Settle.

Immediately east of Settle lies a ridge of high ground running in a general east-and-west direction, known as the High Hills. This ridge rises into three eminences, named 'Low High Hill,' 'Middle High Hill,' and 'High Hill', respectively, on the 6-inch Ordnance Survey map. The ridge forms a narrow tract of ground tapering eastwards. It is bounded on the south by the Middle Craven Fault, and is cut off on the north from the main escarpment of Attermire by the Attermire Fault, which passes close to the Rifle Butts, first described by Prof. J. E. Marr. This ridge has a distinctly 'knoll'-like appearance when seen from the south, as shown in the photograph accompanying Prof. Marr's paper (39, pl. xxiv). This character is especially striking in the case of High Hill itself, which forms the lofty eminence at the eastern end of the ridge. The southern face of the ridge is steep, under High Hill almost precipitous, and the direction of the bedding of the rock is obscure. The northern side of the ridge forms a dip-slope, and its lower portion, at all events near the Attermire Fault, is composed of well-bedded grey limestone, admirably exposed between the old limekiln and Banks Nursery, south of the track leading from Banks Lane to the Rifle Butts. The beds here include layers of pseudo-breccia, and resemble, in all respects, the limestone of D_1 age which forms the main escarpment of the Attermire Fault. Judging from their lithology, they should lie near the horizon of the *Cyrtina-septosa* Band; but the rock is almost devoid of fossils, and there is consequently no definite palæontological evidence of its age. It will be remembered, however, that this portion of the northern succession is also very sparingly fossiliferous north of the Attermire Fault. In what follows it will be assumed that this limestone has been correctly assigned to a horizon in D_1 of the Northern Succession. This bedded D_1 limestone, on the northern slope of the High Hills, can be traced southwards up to the summit of Middle High Hill. On the south of the divide, however, though still north of the Middle Craven Fault, the whole of the southern slope of High Hill and most of the lower ground, east of the Roman Catholic Chapel, is apparently composed of knoll-limestone. The rock here includes, as usual, unfossiliferous as well as fossiliferous patches, the former being often well-bedded; and it is not always possible to distinguish this unfossiliferous bedded limestone from the D_1 limestone north of Middle High Hill. It is impossible, therefore, to map a correct line of junction between the two types, owing to the crushed and faulted character of the ground. The most fossiliferous exposure of the knoll-limestone occurs in the road-cutting in High Hill Lane, close to the Roman Catholic Chapel; but fossils may also be collected from the southern face of High Hill.

It is clear, then, that the wedge-shaped track of ground containing the High Hills, lying between the Middle Craven Fault and the Attermire Fault, is composed of knoll-reef limestone on

its southern face and of well-bedded D_1 limestone, belonging to the Northern Succession, on its northern slope. Consequently, the Middle Craven Fault is not here the dividing line between the northern and the southern facies, neither is the Attermire Fault, as suggested by Prof. Marr (39). This close association of knoll-reef limestone with typical D_1 limestone of the North-Western Province brings us face to face with the general problem of the sudden change in the character of the beds from the northern to the southern facies which, as a rule, takes place at the Middle Craven Fault.

The question naturally arises as to the relation of this knoll-reef limestone, which occupies the southern face of High Hill, to the D_1 limestone which forms its northern dip-slope. There appear to be only two possible alternatives: namely, (1) that the knoll-reef limestone, although now separated from the knolls of Stockdale gorge by the Middle Craven Fault, is practically in place, and that it represents a development of a knoll-facies in the Lower *Dibunophyllum* Sub-zone of the Northern Succession, thus indicating a passage here from the northern to the southern facies in D_1 times; or (2) that the knoll-reef limestone forming the southern flank of the High Hills is not of D_1 age, is not in place, and does not pass laterally into the D_1 limestone against which it abuts on the north. In that case its present position must be due either to overlap, or to a fault, presumably in the nature of a thrust. If the first supposition be correct, the knoll-reef limestone forming the southern face of the High Hills will represent some portion of the Lower *Dibunophyllum* Sub-zone, even if it underlies the bedded limestone as it appears to do. It is essential, therefore, to compare the fauna of the knoll-reef limestone of the High Hills with the fauna of other knoll-reefs in districts lying south of the faults.

Two series of knolls have been described by Tiddeman and later authors: one series in the Clitheroe district, and another in the Cracoe district. These two series are usually considered to occur at widely separated horizons in the Lower Carboniferous succession. The Clitheroe knolls were considered by Tiddeman to occur at a lower level than the Cracoe knolls, and were later regarded by Arthur Vaughan as representing horizons in or below the *Seminula* Zone of the Bristol district. The Cracoe knolls, on the other hand, were correlated by Tiddeman with his Pendleside Limestone of Pendle Hill (61, p. 321). Prof. Marr (30) correlates both the Pendleside Limestone and the Cracoe knolls with the Upper Scar or Main Limestone of Ingleborough, and Mr. Cosmo Johns (33) has supported this correlation. If this view be correct, it would place the Cracoe knolls high up in the Yoredale Series, and therefore they would be the equivalent of D_3: that is, the *Cyathaxonia* Beds of Principal T. F. Sibly's Derbyshire sequence. Tiddeman's correlation appears to be supported by the fact that both the Cracoe and the Malham knolls and the Pendleside Limestone are overlain by the Bowland Shales yielding characteristic goniatites. Prof. Marr's correlation has not, so far as we are aware, been

challenged, except by the late Dr. Wheelton Hind (28), who considered the Pendleside Limestone to lie above the Yoredale Series, which would place the Cracoe knolls on a still higher horizon. Unfortunately, no published lists are available, giving an account of the lower knoll fauna of the Clitheroe district, and we have ourselves been able to pay only a brief visit to that area. Though several of the species from the Clitheroe knolls occur also in the Cracoe knolls, notably *Amplexus coralloides* and *Pugnax acuminatus*, there are many others which appear to be limited to the Cracoe knolls; of these we may specially mention the goniatites, *Glyphioceras crenistria* being the most abundant form.

To facilitate comparison of the knoll-reef fauna of the upper horizon with that of the High Hills the lists tabulated on pp. 239–42 have been drawn up. A list of species collected by us from the High Hills occupies the first column: this list is probably by no means exhaustive, as we have been able to devote only such time to collecting as appeared sufficient to establish the general character of the fauna, and a local geologist would doubtless be able to add considerably to the list.

Unfortunately, the collection made by the late Mr. Burrow, of Settle, now in the Sedgwick Museum at Cambridge, does not record exact localities, and it is impossible to draw on it for our present purpose: for, while many of the specimens undoubtedly came from the knoll-reef development in the neighbourhood of Settle, there is no indication as to which was the side of the Middle Craven Fault whence they were collected, and some specimens certainly come from the district north of the Attermire Fault. A list of species from the Craven knolls collected by one of us (E. J. G.), at the time when Tiddeman was engaged on the survey of the district, is embodied in the fourth column. These were all obtained from the surface of the Swinden and Stebden knolls.[1]

The second and third columns record small collections that we have made from the knolls of Malham and Stockdale gorge. They appear to represent the same general horizon as the Cracoe knolls, and also contain similar goniatites. If we compare these lists, we cannot avoid being impressed by the general similarity of faunas obtained from the Cracoe reefs and from the High Hills. This is especially striking in regard to the brachiopods, 35 species being common to both; also, in the case of the lamellibranchs, 9 species are the same: while the paucity of corals in both areas is noteworthy, though *Amplexus coralloides* is not uncommon. But, perhaps, the most significant feature is the occurrence in both localities of *Glyphioceras crenistria*. This species, so far as we are aware, has not been recorded from the Clitheroe knolls, and Mr. W. S. Bisat informs us that *Glyphioceras crenistria* does not occur in that district below the Pendleside Limestone.

It is probable that the rocks in the Craven area belong to more

[1] A few other species are reported by Dr. A. Wilmore (76, p. 560).

List of Fossils from the Knoll-Reef Limestones of :—

I. The High Hills, Settle, north of the Middle Craven Fault.
II. Stockdale Gorge, Scaleber, south of the Craven Fault.
III. Cawden, Wedber, etc, Malham, south of the Craven Fault.
IV. Cracoe, south of the Craven Fault.

	I	II	III	IV
Amplexus coralloides Sowerby	+	...	+	+
Caninia (?) cylindrica (Scouler)	...	+	+	...
Caninia sp.	+	...	+	...
Carcinophyllum sp.	+	...	...	...
Clisiophyllum sp.	+	...	...	...
Cyathophyllum cf. *murchisoni* Edwards & Haime	+	...	...	...
Dibunophyllum sp.	+	...	...	...
Favosites parasitica Goldfuss	...	+	...	...
Lithostrotion portlocki (Bronn)	...	+	...	...
Lithostrotion irregulare Edwards & Haime	...	+	...	...
Michelinia (?) glomerata M'Coy	...	...	...	+
Syringopora reticulata Goldfuss	...	...	...	...
Zaphrentis sp.; probably a new sp.	+	...	...	...
Zaphrentis cf. *enniskilleni* Edwards & Haime	+	...	...	...
Zaphrentis nodosa (Smythe)	...	+	...	...
Zaphrentis cf. *omaliusi* Edwards & Haime	...	+	...	...
Athyris expansa (Phillips)	+	...	+	+
Athyris globularis (Phillips)	+	...	...	+
Athyris lamellosa L'Eveillé	...	...	...	+
Athyris planosulcata (M'Coy)	+	+	...	+
Athyris sp.	...	...	...	+
Chonetes buchiana L. G. de Koninck	...	...	...	+
Chonetes comoides Sowerby	...	...	+	...
Cyrtina 'septosa' Phillips: very transverse form	+	+	...	...
Dielasma hastatum (Sowerby)	+	+	+	+
Dielasma sacculum (Martin)	+	+	...	+
Martinia glabra (Martin)	+	+	+	+
Orbiculoidea nitida (Phillips)	...	...	...	+
Avonia semicostata Muir-Wood (MS.)	+	...	...	...
Avonia youngiana (Davidson)	+	...	...	+
Buxtonia scabricula (Martin)	+	...	...	+
Buxtonia sp. nov. Muir-Wood (MS.)	+	+	...	...
Overtonia fimbriata (Sowerby)	+	+	+	+
Overtonia laciniata (?) (M'Coy)	+	...	...	...
Productus antiquatus Sowerby	+	+	+	+
Productus 'cora' (?) A. d'Orbigny	+	...	...	...
Productus corrugatus M'Coy	+	...	+	...
Productus corrugatus (?) M'Coy	...	+	...	+
Productus derbiensis sp. nov. Muir-Wood (MS.)	+	+	...	...
Productus cf. *giganteus* Martin	+	...	+	...
Productus griffithianus (?) L. G. de Koninck	...	...	...	+
Productus hemisphericus group, Sowerby	+	...	...	+
Productus longispinus group, Sowerby	...	+	...	...
Productus margaritaceus Phillips	+	+	+	...
Productus maximus M'Coy	+	...	...	...
Productus multispinifer sp. nov. Muir-Wood (MS.)	...	...	+	+
Productus quadratus sp. nov. Muir-Wood (MS.)	+	...	+	+
Productus cf. *rotundus* Garwood	...	...	...	+
Productus semireticulatus var. Martin & Davidson	...	...	...	+
Productus sulcatus Sowerby	...	+	+	+
Productus striatus Fischer	+	...	+	+
Productus striatus group	...	...	+	...
Productus undatus Defrance	...	+	...	...
Productus sp. nov. Muir-Wood (MS.)	...	...	+	...
Proboscidiella proboscidea P. de Verneuil	+	...	...	...

	I	II	III	IV
Pustula aculeata (Martin)	...	+	...	+
Pustula carringtoniana (Davidson)	...	...	+	...
Pustula defensa Ivor Thomas	...	+	...	...
Pustula interrupta sp. nov. Muir-Wood (MS.)	...	+	...	...
Pustula elegans (M'Coy)	+	...	...	...
Pustula keyserlingiana (L. G. de Koninck)	...	...	+	...
Pustula mesoloba (Phillips)	+	+	...	+
Pustula magnituberculata Ivor Thomas	...	...	...	+
Pustula nystiana (L. G. de Koninck)	...	...	+	...
Pustula pilosa Ivor Thomas	...	...	...	+
Pustula plicatilis (Sowerby)	+	+	...	+
Pustula punctata (Martin)	+	...	...	+
Pustula punctata group	...	+	+	...
Pustula pustulosa (Phillips)	...	...	+	...
Pustula rugata (Phillips)	+	...	...	+
Pustula spinulosa (Sowerby)	...	+	...	+
Pustula subelegans Ivor Thomas	...	...	...	+
Sinuatella sinuata (L. G. de Koninck)	+	...	...	...
Pugnax acuminatus (Martin)	+	+	+	...
Pugnax pleurodon (Phillips)	+	+	...	+
Pugnax pugnus (Martin)	+	+	+	+
Pugnax pugnus (?) (Martin)	+	...	...	...
Reticularia lineata (Martin)	+	+	+	+
Reticularia lineata var. *imbricata* (Sowerby)	+	...	...	...
Reticularia reticulata (M'Coy)	+	...	...	+
Retzia ultrix L. G. de Koninck	+	...	...	...
Retzia radiata Phillips	...	+	...	...
Rhipidomella michelini (L'Eveillé)	...	...	...	...
Schellwienella senilis (Phillips)	+	...	+	+
Schellwienella senilis (?) (Phillips)	+	...	...	...
Schizophoria resupinata (Martin)	+	+	+	+
Schizophoria var. *connivens* (Phillips)	...	...	+	...
Schizophoria var. *gibbera* (Portlock)	...	...	...	+
Spirifer acutus Martin	...	+	...	...
Spirifer bisulcatus Sowerby	+	+	+	+
Spirifer (Fusella) convolutus (?) Phillips	...	...	...	+
Spirifer crassus L. G. de Koninck	+	+	+	+
Spirifer crassus (?) L. G. de Koninck	...	+	...	. .
Spirifer duplicicostus Phillips	+	+	...	+
Spirifer duplicicostus (?) Phillips	+	...	...	...
Spirifer (Fusella) grandicostatus M'Coy	+	...	+	+
Spirifer (Brachythyris) ovalis Phillips	+	+	+	+
Spirifer (Brachythyris) pinguis Sowerby	+	...	...	...
Spirifer rhomboideus Phillips	...	+	...	...
Spirifer striatus Martin	+	+	...	+
Spirifer subconicus Martin	...	...	+	...
Spirifer (Fusella) triangularis (Martin)	+	+	...	+
Spirifer (Fusella) trigonalis Martin	...	...	+	...
Spirifer sp.; see note	+	...	...	...
Spiriferina octoplicata Sowerby	+	...	...	...
Syringothyris cuspidata (Martin)	...	+	...	+
Hemitrypa sp.	+	...	+	...
Hemitrypa hibernica M'Coy	...	...	+	...
Penniretepora sp.	...	+	...	...
Aviculopecten clathratus (M'Coy)	+	...	...	+
Aviculopecten fimbriatus (Phillips)	+	...	...	+
Aviculopecten forbesii (M'Coy)	...	...	...	+
Aviculopecten interstitialis (Phillips)	+	...	...	+
Aviculopecten jonesii (M'Coy)	...	...	...	+
Aviculopecten murchisoni (?) (M'Coy)	...	...	...	+
Aviculopecten plicatus (Sowerby)	...	...	...	+
Aviculopecten ruthveni (?) (M'Coy)	...	...	...	+

	I	II	III	IV
Aviculopecten semicostatus (Portlock)	...	...	...	+
Aviculopecten stellaris (Phillips)	...	...	...	+
Aviculopecten tabulatus (M'Coy)	+	...	...	+
Aviculopecten sp.	...	+	...	...
Allorisma sp.	...	+	...	...
Cardiomorpha orbicularis M'Coy	...	...	...	+
Cardiomorpha sp.	+	...	...	...
Conocardium alæforme Sowerby	+	...	...	+
Conocardium sp.	+	...	...	...
Edmondia unioniformis (Phillips)	+	...	...	...
Edmondia sulcata (Phillips)	...	+	...	...
Eumicrotis hemisphericus (Phillips)	...	...	...	+
Eumicrotis sp.	...	...	...	+
Leiopteria lunulata (Phillips)	...	...	...	+
Leiopteria squamosa (Phillips)	...	...	...	+
Leiopteria laminosa (Phillips)	...	...	...	+
Limatulina alternata (M'Coy)	...	...	...	+
Limatulina sp. (?); new, very inflated	...	...	...	+
Modiola sp.	..	...	...	+
Myalina lamellosa L. G. de Koninck	...	+	...	+
Myalina peralata L. G. de Koninck	...	...	...	+
Myalina verneuili (M'Coy)	...	...	...	+
Mytilimorpha rhombea (Phillips)	...	...	...	+
Parallelodon reticulatus M'Coy	...	...	...	+
Parallelodon bistriatus (Portlock)	...	+	...	+
Parallelodon cingulatus M'Coy	...	...	...	+
Parallelodon corrugatus L. G. de Koninck	...	...	...	+
Parallelodon haimeanus L. G. de Koninck (=*multilineatus*)	...	...	...	+
Parallelodon obtusus (Phillips)	...	...	...	+
Parallelodon squamifer (Phillips)	...	+	...	+
Parallelodon sp.	...	...	+	+
Pinna flabelliformis (Martin)	+	...	...	+
Posidoniella vetusta (Sowerby)	+	+	...	+
Posidoniella pyriformis Hind	...	+	...	+
Posidoniella sp.	...	...	...	+
Posidonomya becheri Bronn	...	...	...	+
Pseudamusium ellipticum (Phillips)	...	...	...	+
Protoschizodus axiniformis (Portlock)	...	...	...	+
Protoschizodus æquilateralis (M'Coy)	...	...	...	+
Protoschizodus magnus (?) L. G. de Koninck	...	...	...	+
Pterinopecten concavus (M'Coy)	...	...	...	+
Pterinopecten concentrico-lineatus Hind	...	...	...	+
Pterinopecten granosus (Sowerby)	...	...	...	+
Pterinopecten rigidus (M'Coy)	+	+	...	...
Pterinopecten sublobatus (Phillips)	...	...	...	+
Pterinopecten tessellatus (Phillips)	+	...	...	...
Sanguinolites argutus (Phillips)	...	...	...	+
Sanguinolites angustatus (Phillips)	+	...	...	+
Sanguinolites striatolamellosus (L. G. de Koninck)	...	...	...	+
Sanguinolites striatogranulatus Hind	...	...	...	+
Sanguinolites tricostatus (Portlock) = *striatogranulatus*, according to Hind	...	...	...	+
Streblopteria ornata (Etheridge)	...	...	...	÷
Bellerophon costatus Sowerby	...	...	...	+
Bellerophon tenuifascia Sowerby	...	...	+	...
Bellerophon sp.	...	+	...	...
Capulus angustus (Phillips)	...	+	...	+
Capulus sp.	+	...	...	+
'*Cirrus*' *spiralis* Phillips	+	...	...	...
Euomphalus acutus (Sowerby)	...	...	...	+
Euomphalus pentangulatus Sowerby	...	...	...	+
Euphemus d'orbignyi (Portlock)	...	...	...	+

	I	II	III	IV
Flemingia prisca (M'Coy)	...	...	...	+
Flemingia gemmulifera (Phillips)	...	...	...	+
Lepetopsis retrorsus (Phillips)	...	...	+	+
Loxonema constrictum (Martin)	+	...	...	+
Loxonema rugiferum (Phillips); very poor specimen.	...	...	...	+
Loxonema scalaroideum (Phillips)	...	...	...	+
Luciella limbata (Phillips)	...	...	...	+
Macrochilina conspicua L. G. de Koninck (=*imbricata* of Phillips; *non* Sowerby)	...	...	...	+
Macrochilina acuta (Phillips)	...	...	...	+
Macrochilina rectilinea (?) (Phillips)	+	...	...	+
Metoptoma imbricata Phillips	...	...	+	+ +
Metoptoma pileus (Phillips)	...	...	+	+ +
Metoptoma sp. (?) new	...	...	...	+
Mourlonia carinata (Sowerby)	+	...	...	+
Mourlonia cirriformis (Sowerby)	...	...	...	+
Mourlonia conica (Phillips)	+	...	+	+
Mourlonia concentrica (Phillips)	...	...	...	+
Mourlonia expansa (Phillips)	...	...	+	+
Mourlonia vittata (Phillips)	...	...	...	+
Mourlonia sp.	+	...	...	...
Murchisonia sp.	...	...	+	...
Naticopsis ampliata (Phillips)	...	...	+	+
Naticopsis elliptica (Phillips)	...	...	...	+
Naticopsis planispira (Phillips)	...	...	...	+
Naticopsis tabulata (Phillips)	...	...	...	+
Naticopsis variata (Phillips)	...	+	...	...
Naticopsis sp.	...	...	...	+
Natiria lirata (Phillips)	...	...	...	+
(?) Portlockia æmena L. G. de Koninck	...	...	...	+
Porcellia puzo L'Eveillé	...	...	...	+
Porcellia woodwardi (Martin)	...	...	+	+
Platyschisma glabrata (Phillips)	...	...	...	+
Platyschisma helicoides (Sowerby)	...	...	...	+
Phymatifer pugilis (?) (Phillips)	...	...	...	+
Straparollus dionysii de Montfort	+	...	...	+
Straparollus (?) new; resembles the above, and also *S. mamula* L. G. de Koninck	...	...	...	+
Straparollus sp.	+	...	...	+
Schizostoma catillus (Martin)	...	...	...	+
Turbonitella biserialis (Phillips)	...	+	+	+
Waagenella ferussaci (A. d'Orbigny)	...	...	...	+
Orthoceras cinctum Sowerby	...	...	...	+
Orthoceras gesneri Martin	...	...	...	+
Orthoceras spp.	+	+	+	+
Poterioceras fusiforme (Phillips)	...	...	...	+
Cœlonautilus subsulcatus (Phillips)	...	...	...	+
Discites (Discitoceras) sulcatus (Sowerby)	...	...	+	+
Solenocheilus cyclostoma (Phillips)	...	...	...	+
Nautilus edwardsianus L. G. de Koninck	...	...	...	+
Nautilus ingens Martin	...	...	+	+
Dimorphoceras gilbertsoni (Phillips)	...	...	...	+
Gastrioceras sp.	+	...	...	...
Glyphioceras excavatum (Phillips)	...	...	...	+
Glyphioceras crenistria (Phillips)	+	?	+	+
Glyphioceras micronotum (Phillips)	...	...	...	+
Glyphioceras obtusum (Phillips)	...	...	...	+
Glyphioceras sphericum (Martin)	...	+	+	...
Glyphioceras striatum (Sowerby)	...	+	+	...
Glyphioceras sp.	...	...	+	...
Goniatite sp.	...	+	...	...
Nomismoceras vittigerum (Phillips)	...	...	...	+
Subclymenia evoluta (Phillips)	...	...	...	+

than one horizon in the *Dibunophyllum* Zone; but the species quoted in the list were all collected from the white limestone forming the surface of the Swinden and Stebden knolls. It seems difficult, then, to avoid the conclusion that the knoll-reef limestone on the High Hills is at the same general horizon as the white limestones of the Cracoe knolls; and, if the horizon of the latter be accepted as that of the Pendleside Limestone, or even as low as D_2, it is obvious that the knoll-reef development on the southern flank of the High Hills cannot be of the same age as the bedded D_1 limestone forming its northern slope: it does not, therefore, represent a knoll-development in that limestone, or a natural passage here from the northern to the southern type.[1]

In discussing the question of the passage from the northern to the southern type, it is important to bear in mind that the marked difference in the character of the beds, on the two sides of the Middle Craven Fault, is not confined to the horizon of the knoll-reef limestones (although it is this development which is generally cited in that connexion) but is found throughout the Lower Carboniferous succession, so far as the horizons exposed near the fault are concerned. As shown in the preceding pages, it seems impossible to account for this marked and sudden change throughout the succession by assuming that we have here a passage from the northern to the southern type in D_1 times.

A further aspect of the case may be mentioned here. If, instead of comparing the succession from below upwards, we compare it from above downwards, we see that the highest limestone found in the Northern Succession below the Millstone Grit is the Main Limestone of Ingleborough, while the highest limestone south of the fault is the knoll-reef limestone. If, then, the knoll-reef limestone of Cracoe, Malham, and Stockdale Gorge is of D_1 age, there is nothing to represent the whole of the Yoredale succession on the south side of the fault except the Bowland Shale, which on Pendle Hill immediately overlies the Pendleside Limestone, and this latter should then be also of D_1 age.

As is well known, the Millstone Grit facies comes on at different horizons in different districts, and there appears to be an undoubted overlap of the Millstone Grit over the Yoredale Beds west of Pateley Bridge; but we are now dealing with the beds below this horizon on opposite sides of the fault, and within a few hundred yards of one another.

If the facts set out above have been correctly interpreted, it is evident that the knoll-reef limestones on High Hill cannot be in place among the D_1 limestones, and we are forced to consider the possible alternatives, namely:—(1) that they are substantially in

[1] The only horizon in the Northern Succession where the fauna shows any approach to the knoll-reef type occurs in the Bryozoa Series, high up in D_2, as described on p. 223.

place, and are due to an overlap of D_3 limestone of southern type on to D_1 beds of northern facies; or (2) that they have been brought into their present position by subsequent earth-movements.

So far as the first suggestion is concerned, there is no evidence in its favour; on the contrary, the knoll-reef beds forming the southern flank of High Hill should, on the field evidence, underlie the D_1 limestone which dip off it northwards. Neither is there any evidence of overlap of knoll-reef limestone anywhere in the district south of the fault. We think, therefore, that this alternative may be rejected.

We are left, then, with the only other possibility: namely, that the knoll-reef limestone on the High Hills has been faulted or thrust into its present position. The absence of any other occurrence of knoll-reef limestone north of the Middle Craven Fault would seem to be in favour of this view; but, when we try to locate the position of the thrust in the field, we are bound to admit that no definite line of movement can be traced on the ground. The nearest approach to a line of disturbance between the knoll-reef limestone and the bedded D_1 pseudo-breccias is the presence of a layer of dolomitized and silicified limestone, which occurs near the summit of the ridge, beside the wall which runs up the southern flank of High Hill. This layer can be traced eastwards at intervals, sloping down towards the old limekiln, a short distance north-east of the Roman Camp, where it terminates against a north-and-south fault (Pl. XIV, fig. 2). This layer of dolomites does not, however, appear to be confined to a definite plane, but is more of the nature of a vein altering and impregnating the limestone at slightly different horizons. Similar impregnations of dolomite and silica occur commonly along the southern flank of this range, especially on Low High Hill above the old quarry near the chapel, and again at the back of Castlebergh. Here the alteration appears to mark the position of small faults, and similar mineralization occurs near the old trial for copper on the western shoulder of High Hill. In many places, this altered limestone contains bipyramidal quartz-crystals. It is evident, then, that the High Hill ridge has undergone much crushing and faulting, and represents in reality a 'crush-breccia' on a considerable scale. It is possible that a definite line of thrusting could not be expected in so crushed a region. At the same time, it might be said that there is nothing in the nature of the disturbances actually visible which might not be accounted for by proximity to the Middle and the South Craven Faults. In this connexion we may return for a moment to the Scaleber district, south of the Middle Craven Fault. Here, it will be remembered, a large mass of dolomite occurs above Scaleber Quarry, which seems to have a horizontal rather than a vertical development. If thrusting has taken place in the district, the presence of this dolomite would seem to be more consistent with such movements than with any disturbance caused by the Middle Craven Fault, assuming that fault to be a normal one.

Sugar Loaf Hill.

The country east of the High Hills is also exceedingly puzzling, and is again cut up by faults. The ridge of the High Hills terminates at its eastern end abruptly, where a depression occurs running north-north-west and south-south-east, towards which the beds north of the ridge dip at 10° to 40°. This depression appears to occupy a fault-line, along the east side of which the beds are silicified. About 350 yards farther east the beds terminate abruptly against the western margin of the alluvial flat, which apparently represents the site of an old glacial lake. This evidently marks the line of another north-north-westerly and south-south-easterly fault. The strip of ground between these two faults is occupied by two conical hills, that on the north being known as Sugar Loaf Hill. The depression between them appears also to be due to a fault running roughly east and west, as shown by the dips. Sugar Loaf Hill is composed of a dark limestone, which dips in a general east-north-easterly direction. It is cut off on the north by the Attermire Fault. The beds on the north-west side of the hill, exposed in a small quarry, contain Rhynchonellids and algal nodules, which latter (under the microscope) show well-developed *Girvanella* tubes. On the north-east the beds which dip steeply to the fault, are richly fossiliferous, and contain abundant specimens of *Martinia glabra* and *Spirifer bisulcatus*. On the southern flank of the hill small exposures have yielded numerous specimens of *Entalis ornata*. On account of the uncertainty of the position of the beds in this isolated exposure, cut off as it is on all sides by faults, this area has not been coloured on the maps. We append a list of the fossils collected from here.

Girvanella sp.; form with very fine tubes.
Spongiostroma sp.

Caninia sp.; fragment.

Athyris globularis (Phillips).
Dielasma hastatum (Phillips).
Martinia glabra (Martin); plentiful.
'*Orthotetes*' sp.
Productus concinnus Sowerby.
Productus longispinus group, Sowerby.
Productus muricatus (?) Phillips.
Buxtonia scabricula (Martin).
Pugnax pleurodon (Phillips).
Spirifer bisulcatus Sowerby.
Brachythyris ovalis (Phillips).
Syringothyris sp.; fragments.

Aviculopecten interstitialis (Phillips).
Aviculopecten fimbriatus (Phillips).
Aviculopecten tabulatus (M'Coy).
Aviculopecten semicostatus (?); fragment.
Parallelodon cancellatus (?) (Martin).
Pseudamusium ellipticum (Phillips).

Entalis ornata L. G. de Koninck.

Trilobite-fragments.

Fish-tooth.

Several of these species occur in the knoll-reef limestone of the High Hills; while *Productus concinnus*, *P. muricatus*, and *Entalis ornata* occur at a high horizon in D_2 elsewhere. This last species has not been met with in the North-Western Province. Phillips records and figures a specimen from Bowland under the name of *Orthoceras dentaloideum*. M'Coy considers this to be a

Dentalium, and records *Dentalium dentaloideum* as occurring abundantly in the limestone at Lowick (Northumberland). L. G. de Koninck suggests that the Lowick form is identical with his species *Entalis ornata*, and the form recorded in our list appears to be most nearly allied to de Koninck's species.

The white limestone forming the eminence immediately south of Sugar Loaf Hill appears to belong to the knoll-reef type of the High Hills. The exposures farther east in Stockdale (at Halsteads) include a limestone conglomerate; but they are almost devoid of fossils, and yield no information as to their age nor as to whether they belong to the succession north or south of the fault.

(2) The Bordley District.

In the description of the district between the faults, east of Settle, an outlier of Bowland Shale was mentioned as occurring between Bordley and the Middle Craven Fault. This outlier occupies the surface on both sides of Bordley Beck, immediately south of Bordley Hall. The main exposure lies west of the beck, and forms a semicircular tract of ground having a length of about $1\frac{1}{4}$ miles from east to west, where its southern margin abuts against the Middle Craven Fault, and a maximum width from north to south of about half a mile. Good exposures occur in Moor Close Gill and in its eastern tributary; but the country east of Bordley Beck is almost entirely obscured by drift. According to the Geological Survey map, the Bowland Shale is here brought against the 'Pendle Grit-with-Sandy Shales' on the south, by the Middle Craven Fault. This fault is, however, dying out here, and there is only a slight difference in the horizons on the two sides of the fault; while a short distance east of Bordley Beck the fault is bordered on both sides by the Millstone Grit. The Bowland Shale evidently comprises a fairly thick series of beds, although the base is not seen. The shale is for the greater part devoid of fossils; but occasional layers occur, containing abundant though badly-preserved specimens of *Posidonomya membranacea* and *P. lævis*, together with traces of crushed goniatites. The most fossiliferous bed crops out a short distance above the waterfall in Moor Close Gill, apparently in the lower portion of the series. Farther up stream, some of the 'bullions' in the shale contain well-preserved specimens of *P. lævis* and a few small goniatites. Mr. Cosmo Johns states that he has collected specimens of *Glyphioceras diadema* and *G. reticulatum* from the shale in Moor Close Gill (35).

[During the visit of the Yorkshire Geological Society in June 1922, Mr. W. S. Bisat collected an interesting new species of goniatite from this locality—*Glyphioceras malhamense* Bisat (MS.)—and he has also identified the same species in our collection from a neighbouring exposure of the Bowland Shales.—*February, 1924.*]

As shown above, in the description of the area between the faults, the western and northern portion of the district between Gordale and Bordley—that is to say, all the district, except the portion which is occupied by the outlier of Bowland Shale under description—is composed of rocks belonging to the North-Western Province facies, which comprise the beds between the horizons of the *Cyrtina-septosa* Band and the *Orionastræa* Band. According to the Geological Survey map, the outlier of Bowland Shale appears to follow this Northern Succession conformably, and to pass up, also conformably, into the overlying 'Pendle Grit-with-Sandy Shales' a short distance east of Bordley Beck. So far as the relation of the Bowland Shales to the overlying grits is concerned, this is probably correct; but it is by no means the case as regards the relation of the Bowland Shales to the underlying limestone massif.

Detailed mapping of definite horizons in the Northern Succession brings out the fact that the dip and strike of these rocks are entirely discordant with those of the overlying Bowland Shales, and that the two series have no direct stratigraphical relation one with the other. On the western margin of the Bowland Shales, near the head of Moor Close Gill, the upper pseudo-breccias of D_1 above the *Cyrtina* Band, together with the overlying Lower *Lonsdalia* Beds, are seen trending south-eastwards and terminating abruptly at a short distance from the visible margin of the shales. Farther north the Bryozoa Series, the compact black limestone with *Productus latissimus* and *P. edelburgensis*, and even the base of the overlying cherty *Orionastræa* Band, can be seen cropping out above the waterfall in Moor Close Gill, within a few yards of the margin of the Bowland Shales. East of Moor Close Gill a patch of Bowland Shale is seen apparently overlying the massive crinoidal beds of the Bryozoa Series. It is evident, then, that unless a curved normal fault forms the western and northern boundary of the Bowland Shales, of which no trace can be seen in the field, that these shales must here rest discordantly upon different horizons of the Northern Succession. In the absence of any evidence of normal faulting along the margin of the shales, only two hypotheses seem possible to explain the relationships of the two series: namely (1) an overlap of the Bowland Shales over the various members of the Northern Succession; or (2) a thrust-junction between the two series. Unfortunately, there is no direct evidence as to which of these hypotheses is correct, and either explanation is actually possible.

The presence of Bowland Shales here on the north side of the Middle Craven Fault is certainly unexpected, only one other small patch: namely, that lying east of Threshfield, being known. On the southern side of the fault, at Scaleber and Malham, the Bowland Shale appears to succeed the knoll-reef limestone which (it will be remembered) was correlated by R. H Tiddeman with the Cracoe knolls. It must be admitted, however, that there is

no direct evidence of a thrust-plane at the base of this outlier of Bowland Shales at Bordley, the nearest approach to evidence of thrusting in the district being the crushed character of the shaly limestone which is seen at the base of the cliff on the right bank of Heber Beck. At their southern margin the beds turn over, and dip rather steeply southwards; but this might be accounted for by their proximity to the fault. The exposure of the shaly limestone in Heber Beck is only a small one, and it is not easy to determine the horizon to which it belongs. It may and probably does belong to D_2 of the Northern Succession. The following species have been collected from it:—

Girvanella sp.; in nodules.

Zaphrentis costata M'Coy.
Zaphrentis densa Carruthers.
Zaphrentis cf. *enniskilleni* Edwards & Haime.

Spirifer bisulcatus Sowerby.
Spirifer humerosus Phillips.
Spirifer triradialis Phillips; poor.
Productus sulcatus Sowerby.
Productus tissingtonensis Sibly.
Rhipidomella michelini (L'Eveillé).

The fauna as a whole is fairly characteristic of the Lower *Lonsdalia* Beds; but the Zaphrentids suggest rather a high horizon in D_2, and the absence of *Productus giganteus* and *P. latissimus* is noteworthy. The beds, however, appear to belong distinctly to the northern facies, and may be an eastward continuation of the D_2 beds of Cow Gill waterfall. Their relationship to the Bowland Shales which crop out in the hill above them cannot be ascertained, and it is possible that the crushing that they have undergone is due to slips. It is impossible, therefore, to be certain of the relationship of the Bowland Shales to the rocks of the Northern Succession at Bordley; and, in the absence of evidence for thrusting, it would appear that the Bowland Shales may be overlapping on the northern series.

Still farther east, and about a mile east of Threshfield, there is an outcrop of Bowland Shales containing *Posidonomya membranacea* and crushed goniatites on the northern bank of the Wharfe, opposite St. Michael's Church, Linton. This exposure lies north of the Craven Fault, and about a fifth of a mile below the Tin Bridge at Linton Mill, where the outcrop of the *Cyrtina-septosa* Band occurs. As the *Cyrtina* beds are striking in a direct line for the shales, and as both formations crop out on the same contour, it is impossible that these shales can represent any horizon in the northern Yoredale succession, and they evidently occupy their present position as a result either of overlap, or of thrusting.

VI. The Greenhow Hill District, and its Bearing on the Origin of Knoll-Structure.

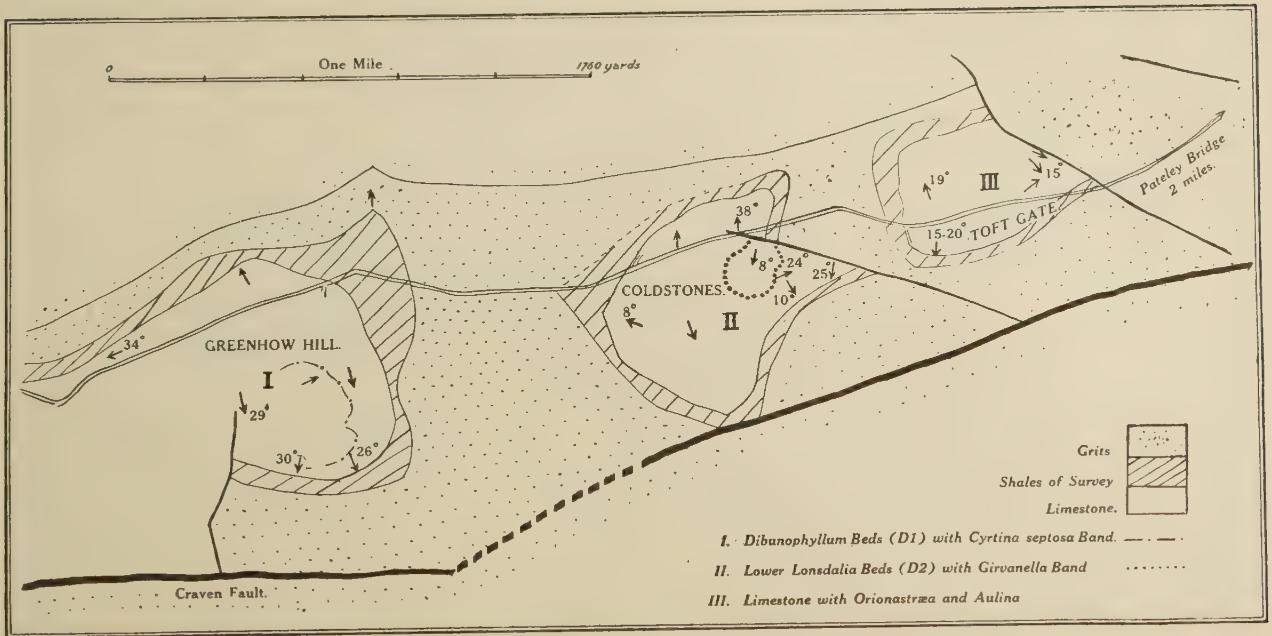
Although the detailed survey of the country undertaken by us does not extend beyond the valley of the Upper Wharfe, something may be said regarding the eastern extremity of the limestone outcrop in the neighbourhood of Greenhow Hill, as the exposures

here throw considerable light on the mode of origin of the limestone-knolls in the Malham and Cracoe districts. East of Grassington and north of the Craven Faults, the Carboniferous Limestone forms a continuous outcrop as far as Keld Houses on Greenhow Hill, where the limestone is folded into a dome which forms a marked feature, resembling in outline the typical knolls of the Cracoe district.

East of Greenhow Hill two inliers of limestone are represented on the Geological Survey map. Both of these occur as low hills, and both show a general quaquaversal dip. We may speak of these three domes as Greenhow, Coldstones, and Toft Gate, the last being situated about 2 miles west of Pateley Bridge (see fig. 1, p. 250). On the Survey map the Coldstones and Toft Gate inliers and the eastern margin of Greenhow Hill are represented as dipping under shale, which in turn is succeeded by grits that appear to occupy the greater part of the surface between the three limestone exposures. Although grit evidently occurs here, the shale which appears on the map as dipping off the limestone cannot be traced in the field. From the mapping it is evident that the surveyor regarded the succession as the same in each of the three exposures, the limestone representing the summit of the massif; and it is probable that, in his interpretation of the district, he was influenced by his experience in mapping the knolls in the Cracoe district farther south-west. A glance at the geological map of the district shows that, south-west of Greenhow Hill and south of the Craven Fault near Skyreholme, east of Troller's Gill, an exactly similar structure is to be found: namely, a dome-shaped mass of limestone dipping under Bowland Shale, which is, in turn, surmounted by grits. Judging from the map, it would seem natural that the succession on the two sides of the fault was the same, and that the outcrops had been shifted by the Craven Fault. A careful examination of the beds, however, quickly dispels the illusion. The fauna of the Skyreholme knoll and Troller's Gill is a typical knoll-reef fauna belonging to the southern type, and includes specimens of *Pugnax acuminatus*; while the limestone forming the domes at Greenhow Hill, Coldstones, and Toft Gate shows an equally typical North-Western Province facies. The latter, therefore, are not 'reef-knolls' in the sense in which the term was used by R. H. Tiddeman for the structures south of the Craven Faults at Cracoe, yet they show quaquaversal dips and weather into knoll-like forms. There can be little doubt that here the 'knolling' on both sides of the fault is due to the disturbances in the neighbourhood of the fault. This conclusion is confirmed by a detailed examination of the domes in the Greenhow district. Careful fossil-collecting from the three domes at Greenhow Hill, Coldstones, and Toft Gate shows that not only do they belong to the North-Western Province facies, but that the limestone in the three domes is assignable to three different horizons in the Northern Succession.

Thus, the limestone of Greenhow Hill is composed of beds

Fig. 1.—*Sketch-map of limestone domes representing three different horizons in the North-Western Province facies; west of Pateley Bridge.*



belonging to the Lower *Dibunophyllum* Sub-zone; the middle dome (known as Coldstones) is formed of typical D_2 beds with *Lonsdalia floriformis*; while the easternmost dome at Toft Gate represents a still higher horizon, at or above the level of the Hardraw Scar Limestone, and contains *Orionastræa phillipsi*. Greenhow Hill is composed of pale-grey limestone characteristic of the Lower *Dibunophyllum* Sub-zone, and the horizon can be exactly determined, as the beds include a typical development of the *Cyrtina-septosa* Band with its characteristic fauna. This band is well exposed in a trench on the southern slope of the hill, behind Duck Street Farm, and good specimens may be obtained from the trench and from the wall close by. The beds exposed in the new quarry above dip under this *Cyrtina* Band, so that the main mass of limestone forming the hill must be well down in D_1.

The limestone of the Coldstones dome is entirely different, and consists of dark earthy and somewhat bituminous limestone with shaly partings, typical of the D_2 beds of the North-Western Province. The limestone has been extensively quarried, and affords excellent exposures of the Lower *Lonsdalia* horizon with its characteristic fauna. The corals, including both single and compound forms, are exceptionally prolific, especially the reef-like masses of *Cyathophyllum regium*. Among the brachiopods the most noticeable feature is the abundance of rolled specimens of *Schizophoria resupinata*, which are occasionally coated with *Girvanella*, as also *Fistulipora* and other bryozoa. Nodules occur, too, in the shaly layers which are frequently formed round specimens of *Zaphrentis densa*, similar to those that are found at this horizon on Ingleborough.

The following is a list of the fossils collected from the Coldstones quarries:—

Girvanella sp.

Aulophyllum fungites Edwards & Haime.
Aulophyllum fungites ('tortuous type' of Dr. Stanley Smith).
Caninia cylindrica (Scouler).
Caninia sp.
Clisiophyllum sp.
Cyathophyllum regium Phillips; abundant.
Dibunophyllum turbinatum (M'Coy).
Dibunophyllum rugosum (M'Coy).
Dibunophyllum spp.
Diphyphyllum lateseptatum M'Coy.
Lithostrotion junceum Fleming.
Lithostrotion maccoyanum Edwards & Haime.
Lonsdalia floriformis (Fleming).
Zaphrentis densa Carruthers.
Zaphrentis sp.; small forms, cf. 'bean'-nodules.

Fistulipora sp.
Encrusting bryozoans, much weathered.

Athyris roysii (?) L'Eveillé.
Athyris obtusa M'Coy.
Chonetes sp.
Productus, latissimoid form (probably new, according to Miss Muir-Wood).
Productus cf. *margaritaceus* Phillips.
Productus setosus Phillips.
Productus sulcatus Phillips.
Productus tissingtonensis Sibly.
Productus spp.
Rhipidomella michelini (L'Eveillé).
Schizophoria resupinata (Martin).
Schuchertella radialis (Phillips).
Seminula ambigua (Sowerby).
Spirifer bisulcatus Sowerby.
Spirifer crassus L. G. de Koninck.
Spirifer duplicicostus Phillips.

The bulk of this fauna is identical with that of the Lower

Lonsdalia Beds of the North-Western Province, and the majority of the species occur in the beds of this horizon north of the Craven Faults.

The easternmost exposure, the Toft Gate dome, lies about 2 miles west of Pateley Bridge. The limestone here has been quarried on both sides of the road. The lowest beds consist of massive dark-grey crinoidal limestone, weathering white. The upper layers are less massive and more reef-like; they contain a few chert-nodules and good specimens of *Orionastræa phillipsi*. Specimens of *Aulina rotiformis* and two very beautiful specimens of *Fistulipora* have been collected from the northern exposure, also a few Spirifers. The limestone inlier of Toft Gate, therefore, represents a high horizon in the Yoredale Series (D_2 D_3) definitely above the horizon of the Lower *Lonsdalia* Beds of Coldstones.

It is manifest, then, that the three inliers of limestone at Greenhow Hill, Coldstones, and Toft Gate represent three quite different horizons of the *Dibunophyllum* Zone of the northern succession. It is also clear that, in the area between Thorpe and Pateley Bridge, two sets of limestone domes have been developed, aligned in a general east-and-west direction parallel one to the other on each side of the Craven Fault. Those on the south side belong to Tiddeman's 'knoll-reef' type, and contain the southern fauna; while those on the north side belong to the North-Western Province facies, and are composed of rocks belonging to the *Dibunophyllum* Zone.

Although the domes in the Greenhow district are the most striking examples that we have met with, other, but smaller, instances of 'knolling' in the rocks of the northern facies occur. Thus the beds of the *Michelinia* Zone at Newby Cote are folded into a dome close to the South Craven Fault, and again at Stainforth Bridge against the North Craven Fault. Prof. J. E. Marr's contention, therefore, that limestones can be folded into 'knoll'-like domes independently of their original structure or geological horizon, is fully substantiated. At the same time, it seems probable that the highly specialized examples in the Cracoe district do partly owe their characteristic structure to their original mode of deposition, consisting of an exceptionally rich accumulation of organic remains, notably brachiopod and lamellibranch shells, associated with goniatites and crinoidal débris. This type of accumulation may be paralleled by the accumulation of *Lucina* shells in the Cretaceous beds of Colorado, which gave rise to the structures known to American geologists as Tepee Buttes. In places, where the beds containing these accumulations have been subject to earth-movements, and especially where the limestone has a covering of shale, the original knoll-like structure may well have been emphasized. In this connexion the linear arrangement of the knolls, as also their relation to anticlinal structures pointed out by Prof. Marr (39), appears to be an important feature in the problem that should not be overlooked.

An interesting point regarding the three domes in the Greenhow Hill district is brought out by a study of the Geological Survey map, where the intervals between the three domes are shown as occupied by Millstone Grit, and grits certainly do appear at the surface between Greenhow and Coldstones. This seems to point to an overlap of the grit over the limestone domes; for, as shown above, the three domes represent three different horizons in the Northern Succession. This is confirmed by the mapping of the grit north of the limestone outcrop, where it is represented as resting on successively higher horizons in the Yoredale Series as it is traced from east to west.

VII. Summary and Conclusions.

The detailed examination of the Lower Carboniferous rocks of the Settle area as described in the foregoing pages has led to the following conclusions:—namely, that the whole of the succession as developed north of the North Craven Fault belongs to the North-Western Province facies, and exhibits the same general faunal succession as that already determined for the rocks of the same age in Westmorland; and that the strip of country lying between the Craven Faults is also (for the greater part) characterized by the same type of development, so that the Middle Craven Fault may be taken in general as the southern limit of the North-Western Province facies. At the same time, certain special features are noticeable when we make a detailed comparison of the succession in West Yorkshire with that of Westmorland, namely:—

(1) A more calcareous development in the upper beds of the *Dibunophyllum* Zone in the southern and eastern portions of the area, the intercalated shales and sandstones characteristic of the Yoredale succession in Wensleydale being represented by crinoidal limestone.

(2) The incoming of fragmental shelly deposits in the Upper Yoredale beds, which contain a few species possessing affinities with the knoll-fauna south of the faults. This is especially noticeable in the Bryozoa Series near the summit of D_2 between Stockdale and Bordley.

(3) The occurrence of beds rich in specimens of *Productus pugilis*, overlain by shaly limestone containing *P. latissimus* and *P. edelburgensis* in the upper portion of D_2.

(4) The development of a band characterized by *Orionastræa phillipsi* at the horizon, apparently, of the Simonstone Limestone, which in Wharfedale extends up into the base of the overlying Middle Limestone. This band can be traced as far east as Toft Gate, near Pateley Bridge.

(5) The occurrence, east of Settle in the strip lying between the faults, of patches of rock consisting of knoll-reef limestone and Bowland Shales, which belong essentially to the southern type of development; also the occurrence of a patch of Bowland Shale at Linton, north of the North Craven Fault.

(6) South of the Middle Craven Fault the beds in general show an abrupt change to the southern type of development. In two places, however, in Black Gill Beck near Scaleber Force, and on Low South Bank opposite Stockdale Farm, outcrops of limestone occur containing faunas characteristic of the Yoredale facies north of the fault.

It will be seen, therefore, that the problem of the change from the northern to the southern type of development is a complex one, and that although there is occasionally a slight tendency towards knoll-reef conditions in the higher Yoredale Beds in the district between the faults, there is no place where a gradual lateral change from the northern to the southern type can be traced. The change occurs generally in an abrupt manner along the line of the Middle Craven Fault; but the presence north of this fault of outlying patches of rock belonging to the southern type, and of inliers of Yoredale rocks south of the fault, adds considerably to the difficulty of the problem. In all attempts at a solution it must be borne in mind that the difference in character of the beds belonging to the southern type, from those of the Northern Succession, is both a lithological and a palæontological one, and that the difference is not confined to the horizon of the knoll-reefs, but can be traced throughout the southern series, so far as this is exposed immediately south of the faults. R. H. Tiddeman (66), and more recently A. Vaughan (74), attributed this sudden change of facies to the influence of faulting, which they regarded as having been in operation during the deposition of the beds in Lower Carboniferous times. If this were the case, there must obviously have been a repetition of this movement in post-Permian times, as the Coal Measures and the Brockram Series are brought on a level with beds of Lower Viséan age near Ingleton.

Tiddeman's theory of the origin of knolls requires shallow water for their formation, as he considers that they were accumulated on a shoal of fragments broken up by the waves. As they were formed on the downthrow side of the fault, we cannot well attribute the difference in the character of the fauna to any marked difference in depth on the two sides of the fault. Indeed, from whatever point of view we regard this explanation, it appears impossible to accept it, especially as it does not account for the presence of knoll limestone on the High Hills, nor of Bowland Shales at Bordley, both north of the fault. Prof. J. E. Marr (39), who first pointed out the occurrence of this knoll limestone between Attermire Scar and the Middle Craven Fault in Stockdale, suggested that the Attermire Scar Fault is, in reality, the eastward continuation of the South Craven Fault which runs from Ingleton to Settle, and that the knoll limestones of the High Hills therefore lie south of the Craven Faults; and Mr. Cosmo Johns (33) has supported this view. When mapping this district we had this interpretation constantly in mind as the easiest solution of the problem; but, as shown above, the field evidence does not bear out the suggestion. In the first place, the Attermire Fault cannot be traced west of Banks Nursery, but is blocked by the *Nematophyllum-minus* Beds, which there crop out uninterruptedly across its supposed trend (Pl. X); and secondly, there is a considerable tract of D_1 limestone, south of the Attermire Fault and north of the High Hills, which differs, in no respect that we can ascertain, from the D_1 limestone occurring on Beacon Scar north of the fault.

Indeed, the wedge-shaped strip between the Attermire Fault and the Middle Craven Fault of the Geological Survey Map is the most puzzling tract of country in the whole district, and appears to be largely in the nature of a fault-breccia containing blocks that belong to the rocks of both the northern and the southern facies.

The knoll-reef limestone on the High Hills, as shown by its fauna, is undoubtedly the equivalent of the Cracoe and Malham Knolls, and we have given reasons for concluding that these knolls are of Upper Yoredale age and at least as high in the Carboniferous System as the *Orionastræa* Band of the Northern Succession, which we have tentatively referred to the base of D_3 of Derbyshire.

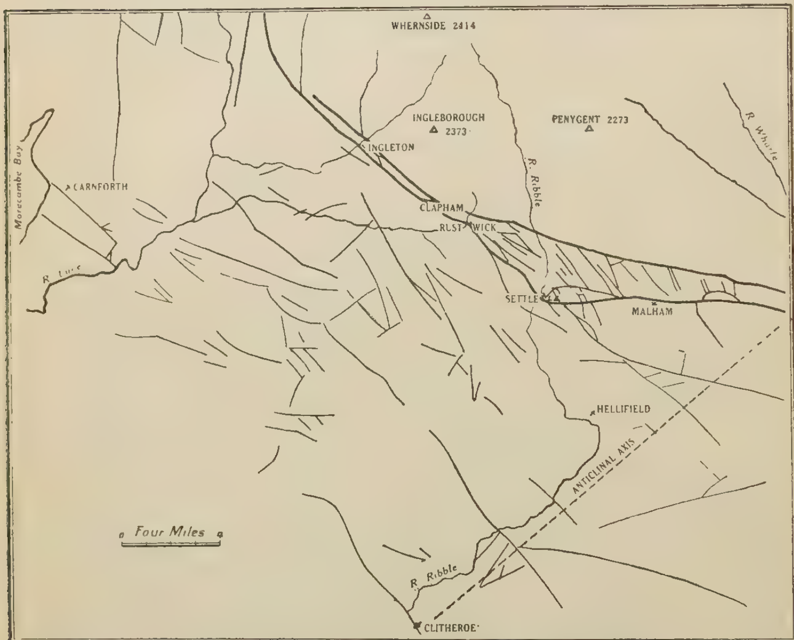
The knoll-reef limestone on the southern flanks of the High Hills, being of D_3 age, cannot pass laterally into the D_1 limestone lying north of it, and the field relation of these two formations precludes the possibility of a simple overlap. There appears to be no alternative explanation, other than that the beds have been brought together by thrusting, though admittedly there is no definite line of thrust that can be satisfactorily traced or mapped in the field. The patches of Bowland Shale belonging to the southern type of development, which lie north of the fault at Bordley and Linton, also present a difficult problem. They are certainly discordant to the beds of the Northern Succession against which they abut; again, however, there is no definite line of thrusting that can be traced, and their relation to the beds of the Northern Succession does not preclude the possibility of a true overlap. Such an hypothesis is not inconsistent with the relation of the Bowland Shales to the underlying beds south of the faults, where the thickness of the shales between the knoll-limestone below and the Millstone Grit Series appears to be a very variable one. That overlap does take place in the upper members of the series is shown by the relation of the Millstone Grit Series to the Yoredale succession west of Pateley Bridge, where it appears to overlap on to the different horizons of the northern series between Greenhow and Kettlewell. The hypothesis that thrusting has taken place along the line of the Middle Craven Fault is not new. Prof. J. E. Marr (39) suggested that the Craven Faults were thrust-faults, and considered that movement had taken place from the north. If we are driven to invoke thrusting to account for the sudden change from the northern to the southern type, and to explain the occurrence of the knoll-limestone at the High Hills, the facts would seem to us to be more easily accounted for by invoking a movement from the south. The change in the character of the deposits, if we exclude Tiddeman's theory of contemporaneous faulting, must have been gradual, and, but for the complications introduced by thrusting, should be traceable somewhere. In this connexion the presence of inliers of Yoredale rocks in the Bowland Shales at Black Gill Beck and Low South Bank is important, suggesting, as they do, an extension of the northern type of development on the south side of the Middle Craven Fault.

The actual extent of the movement need not have been very

great. The introduction of detrital material by rivers, south of an area of clear water, would account for a rapid change in conditions, and would produce a marked change in the character of the fauna. Such a change is postulated by Wheelton Hind & J. A. Howe (28) in their explanation of the origin of the deposits of the Pendleside Series, although they attribute it to a later period.

The evidence derived from the general faulting and folding in the district is also important in this connexion. A study of the

Fig. 2.—*Sketch-map illustrating the general character of the movements in the neighbourhood of the Craven Faults.*



minor faults in the district appears, so far as it goes, to bear out the view of a general pressure coming from the south or south-east. As is well known, there is a marked difference between the tectonic structure of the country lying north of the North Craven Fault, and that lying south of it. The northern district, comprising Ingleborough and the Craven Highlands, forms a rigid block singularly free from folding and faulting, where the beds lie almost horizontal and undisturbed (Marr, 40). The district between the faults, as shown on the accompanying maps, is traversed by numerous subsidiary faults having a general north-north-westerly and south-south-easterly trend. Those in the east of the district have a nearly north to south direction, while the

rest trend increasingly north-westwards, as we approach the western border of the rigid block. These minor faults terminate abruptly against the North Craven Fault, and are either older than the Middle and South Craven Faults, or contemporaneous with them.

Beyond the Craven Faults, in the Millstone Grit district, on the south and west, a similar series of north-north-west and south-south-east faults exist, extending southwards to the Clitheroe Fault and to the north-north-westerly faults bordering the eastern margin of the Burnley Coalfield round Colne. South of the Craven Faults occurs a system of folds the axes of which strike generally in a north-easterly and south-westerly direction, or at right angles to these subsidiary faults. Such a system might be expected, on the supposition of movement from the south and south-east against the rigid block, and may well be due to the same set of movements as that which produced the systems of north-west to south-east faults (see fig. 2, p. 256).

West of the rigid block the country could yield more readily to pressure from the south, and tend to move northwards along the margin of the block: that is, along the South Craven Fault, north of Settle, which would, therefore, be partly, at all events, in the nature of a 'tear'-fault. That such a movement did actually take place is suggested by the presence of the two inliers of brecciated knoll-reef limestone, containing a characteristic knoll fauna, incorporated in the Millstone Grit near Carnforth previously described by one of us (19). This limestone differs entirely from any known horizon in the Northern Succession in the neighbourhood, but resembles the knoll development in the Clitheroe district farther south. Again, the curved northward continuation of the South Craven Fault between Ingleton and Sedbergh, and the wedge of Polygenetic Conglomerate and Lower Carboniferous rocks which border it, taken in conjunction with the sudden change in the character of the Yoredale Beds on each side of it, is much more suggestive of lateral movement than of normal faulting.

The character of the higher beds west of the fault is markedly different from that of the normal Yoredale Beds east of it, less than a mile away. The fauna at Sellet Mill, with its large form of *Schizophoria resupinata*, is strongly reminiscent of the southern type of development near Scaleber; while the whole of the Upper Yoredale limestones are represented by a single band of crinoidal limestone.

In considering the evidence bearing on the hypothesis of horizontal displacement, we may once more refer to the masses of dolomite near Scaleber, to the large spread of altered and silicified rock with kernels of crystalline limestone on High South Bank, and to the patches of dolomitized and silicified rock at the High Hills. These extensive developments of metamorphosed limestone all belong to the Southern Succession, and suggest alteration as the

result of horizontal movement; this cannot be explained as the result simply of changes produced by the Middle Craven Fault, if this fault be considered a normal one.

On the whole, then, taking the general evidence of movement in the district, and having regard especially to the knoll development at the High Hills, to the patches of Yoredale rocks south of the Middle Craven Fault, to the presence of inliers of knoll-limestone near Carnforth, and to the absence of any unfaulted locality where a gradual passage from the northern to the southern type of development can be found, we may consider the problems, as described in the foregoing pages, to be most readily explained by postulating a general movement from the south or south-east against the northern rigid block, the actual lateral displacement being greatest along the margin of the South Craven Fault. The North Craven Fault and the Middle Craven Fault appear to be chiefly in the nature of normal faults, although some lateral displacement may have occurred along the latter.

With regard to the origin of the knoll-reef structure, the evidence obtained in the district specially studied shows that knoll-like masses having a general quaquaversal dip may originate simply as the result of pressure, especially so in the Greenhow district in the neighbourhood of the Craven Fault, where the structures occur in the northern Yoredale succession, affecting different horizons and including considerable masses of well-bedded and poorly fossiliferous rock. At the same time, the typical knoll-reefs which occur in the Southern Succession appear to owe their form, in part at all events, to their original mode of accumulation, as suggested by Tiddeman; but the quaquaversal structure may well have been accentuated by subsequent movements, as shown by the inclusion of tracts of unfossiliferous limestone which cannot be attributed to shelly accumulations.

In putting forward these theoretical considerations, we are fully aware that the hypothesis leaves certain difficulties still unexplained, notably the absence of definite lines of thrust which can be mapped in the field, and we are convinced that no final solution of the problem can be arrived at until the country south of the faults, including the Cracoe area, has been mapped in detail, and the faunal sequence established on a firm basis. To have attempted to supply this deficiency would have unduly delayed the presentation of the main result which we set out to obtain: namely, the southern limit of the North-Western Province facies. We hope, nevertheless, that the results so far achieved may be of value in the final solution of the problems still outstanding.

VIII. Palæontological and Petrological Notes.

(1) Palæontological Notes.

Aulophyllum concentricum sp. nov. (Pl. XVI, figs. 1*a*, 1*b*, & 2.)

It is possible that, after more material has been examined, it will be found necessary to transfer to a new genus the form here referred to *Aulophyllum*, as interpreted by Dr. Stanley Smith (53). Only two specimens of this coral have yet been found —one, a small fragment, and the other —the type —an almost complete corallum, which must have been rolled and subsequently coated with calcareous mud before it was finally buried. The muddy incrustation considerably obscures the calice and central boss. The corallum is cornute, tending to a cylindrical shape: its length is 10 cm., and its width at the calice 4 cm. At a diameter of 3 cm. there are seventy-five major septa. In longitudinal section the tabellæ are seen to be slightly arched, to be closely packed, and sometimes to extend entirely across the central column (fig. 1 *b*). In transverse section they appear as concentric rings, eleven of which are present in the figured section (fig. 1*a*), which has a central column 1·1 cm. in diameter. The characters of the tabellæ are diagnostic of this form. The septal lamellæ are numerous, curved, somewhat spirally arranged, and fewer than the major septa. The wall of the central column is not very strongly developed.

Horizon.—D_1. Nodular Bed. In association with typical specimens of *Aulophyllum fungites* (Fleming).

Locality.—Meal Bank Quarry, Ingleton.

Dibunophyllum vaughani nom. nov. (=' D. θ' Vaughan). (Pl. XVI, figs. 5 *a* & 5 *b*.)

Dibunophyllum bristolense nom. nov. (=' D. ψ' Vaughan, early form). (Pl. XVI, figs. 6 *a* & 6 *b*.)

It is clear that it would be convenient for palæontologists and others who may wish to refer to these two species, if Vaughan's symbols were replaced by specific names. We would, therefore, propose *Dibunophyllum vaughani* for *Dibunophyllum* θ Vaughan (71, p. 283, & pl. xxiv, fig. 1), horizon D_1; Flax Bourton, south-west of Bristol; type-specimen, Brit. Mus. (Nat. Hist.) No. R 15279. Further, we propose *Dibunophyllum bristolense* for *Dibunophyllum* ψ Vaughan (71, p. 284, & pl. xxiv, figs. 2–2 *a*), horizon D_2; Rownham Hill, Leigh Woods, north-west of Bristol; type-specimen, Brit. Mus. (Nat Hist.) No. R 15294.

Vaughan gave figures of transverse sections of *Dibunophyllum* θ and of *D.* ψ in the paper quoted above (71), and later Dixon & Vaughan (14) figured a transverse section of an early form of *Dibunophyllum* ψ from D_1. The differences between the early and late forms of *D.* ψ Vaughan considers to be of degree only: (1) the early form is cylindrical, the late form is conical; (2) the sharp cuspidate boundary of the central area and the Aspidiophylloid characters are more marked in the late form.

Both longitudinal and transverse sections are here given of the two forms of *Dibunophyllum* designated above, which occur together in beds of D_1 age in the Settle district. The transverse sections agree with the descriptions and figures given by Dixon & Vaughan (14); but figures of the longitudinal sections have not hitherto been published. Those here given show the following important differences between the two forms:—In *Dibunophyllum bristolense* the diameter of the central area is greater, the tabular vesicles are more numerous and smaller, and the tabellæ are flatter than is the case with the corresponding structures in *Dibunophyllum vaughani.*

Horizon.—D_1. Nodular Bed.

Locality.—Meal Bank Quarry, Ingleton.

DIBUNOPHYLLUM ASPIDIOPHYLLOIDES sp. nov. (Pl. XVI, figs. 3 *a* & 3 *b*.)

The type-specimen has been much weathered, and the full width of the dissepimental zone is shown only at one point in fig. 3 *a*. Both major and minor septa are present, and the distal halves of the former are considerably thickened. Seen in longitudinal section, the tabulæ are widely spaced, their convex surfaces are directed upwards, and they are so large that usually two are sufficient to bridge the tabular area. The central column is nearly half as wide as the corallite—a character diagnostic of the species. The tabellæ are closely packed, arched, and in longitudinal section do not appear cusped in the mid-line, as they do in other species of *Dibunophyllum.* The central plate is very thin.

Horizon.—D_1. Nodular Bed.

Locality.—Meal Bank Quarry, Ingleton.

DIBUNOPHYLLUM sp., cf. HISTIOPHYLLUM DICKI Thomson. (Pl. XVI, figs. 4 *a* & 4 *b*.)

The transverse section of the type-specimen (fig. 4 *a*) differs from Thomson's figure of *Histiophyllum dicki* (58 *a*) in having less clearly defined septal lamellæ. Thomson does not figure a longitudinal section; but fig. 4 *b* shows that the dissepiments are large, the tabulæ widely spaced, and the central column, the limits of which are ill defined, composed of very irregular tissue.

Horizon.—D_1. Nodular Bed.

Locality.—Meal Bank Quarry, Ingleton.

DIBUNOPHYLLUM sp., aff. D. MATLOCKENSE Sibly. (Pl. XVII, figs. 1 *a* & 1 *b*.)

The specimen described agrees in its transverse section with Dr. Sibly's species *Dibunophyllum matlockense* (51), having minor septa which extend right across, but not beyond, the dissepimental zone. Sibly does not figure a longitudinal section of his species; but fig. 1 *b* shows that in longitudinal section the dissepiments, tabulæ, and tabellæ are very closely packed, and that

each tabella resembles a brace bracket (⏞) with sharply curved ends.

Horizon.—D_2.

Localities.—Above Hunt Pot, Penyghent; Black Rigg Quarry, Feizor, near Settle.

DIBUNOPHYLLUM RHODOPHYLLOIDES sp. nov. (Pl. XVII, figs. 2*a* & 2*b*.)

Corallum cornute, with a thin, but well-defined, epitheca. The type-specimen, where cut just below the calice, has a diameter of 4·5 to 5 cm. (fig. 2 *a*). There are about forty-two major, and as many minor septa, widely spaced, and distally thickened. The cardinal fossula is well developed, and there are traces of alar fossulæ. The dissepiments, as seen in longitudinal section, are almost vertically disposed. The tabulæ are widely spaced, their convex surfaces are usually directed upwards, and are so large that sometimes only one and seldom more than two are sufficient to bridge the tabular area. The diameter of the central column is nearly half of that of the corallum. The septal lamellæ are numerous, but very thin, and sometimes only indicated by the cusp-like intersections of the tabellæ. The tabellæ are closely packed, and each in longitudinal section is seen to form a cusp at the median plate. The median plate is only about 6 mm. long.

This species is assigned to the genus *Dibunophyllum*, because it has a median plate; but in general structure, especially as seen in longitudinal section, it closely resembles *Rhodophyllum*.

Horizon.—D_2.

Locality.—Old Ing, under Penyghent.

RHODOPHYLLUM DISTANS sp. nov. (Pl. XVII, figs. 4 *a*, 4 *b* [type specimen] and Pl. XVIII, fig. 3.)

Thomson figured six species of *Rhodophyllum*, among them an incomplete figure of *Rh. simplex*, to which species the form here described as *Rh. distans* approximates (58, p. 556 & pl. xx, fig. 3 *a*). *Rh. distans*, however, has fewer septa than *Rh. simplex* (the proportions being 7 : 10) and the 'sub-convolute' septal lamellæ are not so regular as those of *Rh. simplex*. The corallum of *Rh. distans* has an epitheca with fine concentric growth-lines, not, however, well shown in the figure (Pl. XVIII, fig. 3). On the convex side is a well-developed cardinal fossula, and there are indications of alar fossulæ. The counter-septum and the cardinal septum are shorter than the other major septa. The minor septa first appear when the corallum reaches a diameter of about 2 cm., and in these earlier stages both major and minor septa are very thick. In a section, cut just beneath the calice, with a diameter of 4 cm., the minor septa are not more than 5 mm. long. In later stages the minor septa and the proximal halves of the major septa (those parts, that is, within the dissepimental zone) become thin and slightly flexuous. The dissepiments are large and very sparse,

forming a series of almost vertically-disposed plates, shown only on one side of the figured section (fig. 4 *b*), which, unfortunately, for the greater part lies in the plane of two opposite septa.

Horizon.—D_2.

Locality.—Above Hunt Pot, and Old Ing, Penyghent.

LOPHOPHYLLUM [KONINCKOPHYLLUM] MAGNIFICUM (Thomson & Nicholson). (Pl. XVII, figs. 3 *a*, 3 *b*, & 3 *c*.)

Under the two names *Koninckophyllum magnificum* and *K. retiforme* Thomson[1] describes and figures two corals, the former having a series of irregularly-disposed dissepiments, as seen in transverse section, and the other a much more regular tissue, described as a 'rectangular series of plates'. A section (fig. 3 *a*), cut from the mature portion of the specimen figured, resembles Thomson's figure of *K. magnificum*; while the section (fig. 3 *b*) cut from the proximal portion of the same specimen at the distance of an inch from the first-mentioned section resembles Thomson's figure of *K. retiforme*, with 'rectangular' dissepiments. In our opinion the two forms should be included in one species, which we would name *Lophophyllum magnificum* (Thomson & Nicholson).

Horizon.—D_2.

Locality.—Above Hunt Pot, Penyghent.

LITHOSTROTION ARACHNOIDEUM (M'Coy). (Pl. XVIII, figs. 4 *a* & 4 *b*.)

The shape of the tabulæ of the specimen figured by us is diagnostic of *Lithostrotion arachnoideum* (M'Coy). The tabulæ are slightly arched peripherally, but nearly flat, or even somewhat depressed when they come into contact with the columella.

Horizon.—Limestone-with-Chert.

Locality.—Scaleber Quarry, Settle, south of the Middle Craven Fault.

ZAPHRENTIS sp., aff. *Z. nodosa* (L. B. Smyth). (Pl. XVIII, fig. 5.)

The figured specimen, with its major septa characteristically thickened, and its short, blunt, minor septa, closely resembles L. B. Smyth's figure of his *Densiphyllum nodosum* (57) from the Rush Slates and Rush Conglomerate (Z_2–Si). It occurs, however, at a considerably higher horizon than Smyth's species.

Horizon.—Knoll-Reef Limestone, Goniatite-Bed.

Locality.—Stockdale Gorge, near Settle.

ZAPHRENTIS spp. (Pl. XVIII, figs. 6 *a*, 6 *b*, 7 & 8.)

In Pl. XVIII, figs. 6 *a* & 6 *b* represent one of the forms (referre to in the fossil lists, p. 202, as *Z.* sp. nov. 1), characterized by its small size and conspicuously long minor septa, and which frequently

[1] 58, p. 124 & pl. xi, figs. 1–2.

forms the nucleus of the nodules enclosing the 'bean-shaped organism' (see p. 203). It is associated with *Z. costata*, *Z. omaliusi*, and a new small species of *Amplexus*. Mr. R. G. Carruthers has identified it with a form said to be common in the shales above the Derbyshire massif.

Pl. XVIII, fig. 7, illustrates a form (referred to on p. 202 as *Z.* sp. nov. 2), apparently related to *Z. densa*, but with well-developed minor septa. It occurs at a somewhat higher horizon than the last, in the Bryozoa Series of Moor Close Gill, Bordley; also in the Lower *Lonsdalia* Beds at Gauber High Pasture.

Pl. XVIII, fig. 8, illustrates a third form (referred to on p. 202 as *Z.* sp. nov. 3), in which the septa are radially arranged, and the minor septa are long (as in the last) and tend to be unattached.

All these forms occur in some abundance in the lower portion of D_2. They are characteristic of the Lower *Lonsdalia* Bed at Keld Sike and Gauber High Pasture under Ingleborough, and Cow Gill waterfall in the Bordley district.

All the specimens figured and described in this paper are contained in Prof. E. J. Garwood's collection, deposited in the Geological Museum at University College, Gower Street, London, W.C. 1.

Petrological Notes.

The Viséan rocks of the Settle district, like those of Westmorland, were deposited during a period of submergence succeeded by a period of emergence, which suggests a rhythmic depression and elevation of base-level, as postulated by Joseph Barrell.[1] The beds also exhibit minor subsidiary rhythms or 'diastems', possibly accompanied by short periods of local erosion.

The beds laid down during the period of submergence are largely calcareous in character, and this is especially marked in the case of the rocks of the *Nematophyllum-minus* and Lower *Dibunophyllum* Sub-zones which have been extensively quarried for lime near Settle and Horton. No sandstones are met with in this portion of the succession. True shales are also absent, though layers of bituminous limestone and calcareous shale occur in the *Michelinia* Zone. Thin layers of ferruginous mudstone are found in D_1, notably near Ribblehead Station and in Meal Bank Quarry, Ingleton, which appear to mark periods of elevation. This mudstone resembles much more closely shales and underclays of the Coal Measures than normal Lower Carboniferous shale; and, if we accept the coal in Meal Bank Quarry as a contemporaneous deposit, the emergence at this period must have given rise to lagoon conditions, unless this coal and mudstone drifted into their present position.

The submergence at the beginning of Viséan times in West Yorkshire appears to have been too rapid for the growth of calcareous

[1] Bull. Geol. Soc. America, vol. xxviii (1917) pp. 776–809.

algæ, as the sea spread over the whole area in *Nematophyllum-minus* times. In one place, however, near Great Stainforth, we find small fossils encrusted with a deposit resembling *Spongiostroma* and badly-preserved remains of *Mitcheldeania*. Oolitic limestone is rare in these beds, but occurs in the *Michelinia* Beds below Thornton Force and at Nappa Scar, where the structure resembles very closely the development at this horizon in Docker Beck in the Shap district. The whole of the succession up to the base of the Yoredale Series is rich in foraminiferal remains.

Fine-grained porcellanous limestone (calcite-mudstone of E. E. L. Dixon) is limited to a definite horizon, namely the basement-bed of D_1, at which level it is usually well developed in the district north of the faults. This porcellanous band is on the same horizon as that of a similar bed already described in the Shap district. It is characterized, as usual, by the abundance of *Calcisphera* and the presence of small gastropods.

The Yoredale succession, north of the faults, consists of alternations of limestone, shales, and sandstones. As a rule, the limestones rest upon sandstones, and are overlain by shale. The sandstone below the limestone may, however, be shaly at the top, and, in the case of the Middle Limestone, there is often (as in Wensleydale and Wharfedale) coal at the base which has been worked at several places. Locally, coal is also met with at the base of the Main Limestone: as on Cam Fell, Widdale Fell, and Whernside.

In the district between the faults east of Settle the sandstone and shale have practically disappeared, and we find an almost unbroken succession of crinoidal limestone up to the *Orionastræa* Band; while in the Bordley district there is a further 50 feet of limestone above this Band.

Chert occurs typically in the *Orionastræa* Band, but is also characteristic of the upper portion of the Bryozoa Series in the district between the faults.

Algal limestones occur at several horizons in the Yoredale rocks, the most notable being at the base of D_2, where the *Girvanella* nodular bed is admirably developed throughout the district. *Girvanella* tubes are also conspicuous in the nodules in the overlying Lower *Lonsdalia* Beds, where they are associated with the 'bean'-like organisms and *Aphralysia*. At a still higher horizon, at the base of the *Orionastræa* Band, *Girvanella* tubes are again occasionally met with, associated with '*Spongiostroma*' structure. The best examples occur in Cow Gill section, near Bordley, where the tubes are found encrusting rock-fragments, and are associated with oolitic grains.

Dolomite occurs under two conditions. Bedded dolomite is rare; but the development of this rock on the horizon of the *Cyrtina-septosa* Band, at Mr. Delany's quarries near Threshfield, appears to be a contemporaneous deposit, as it occurs again at the same horizon at Ghaistrills Strid and also in the Kettlewell district. As a rule, however, in the Settle district dolomite occurs in the

neighbourhood of important faults: as, for instance, near the South Craven Fault at Ingleton, and again in Jenkin Beck, and near the North Craven Fault at Great Stainforth. On the High Hills streaks of dolomite occur in connexion with the cross-faults, and a band of this material may be traced at intervals near the junction of the knoll-reef limestone and the D_1 limestone.

The origin of the mass of dolomite immediately north of Scaleber Quarry and of that which occupies a large area on High South Bank is difficult to explain. These patches are some distance from the Middle Craven Fault, and dolomite is absent from the rocks in immediate proximity to the fault. The dolomite on High South Bank is certainly secondary, as kernels of unaltered limestone can occasionally be seen. It is possible, then, that these two exposures may be connected with thrusting in the district.

Silicified limestones, containing well-grown bipyramidal quartz-crystals, which frequently show a definite zonal structure, are found in several portions of the district. The most striking development occurs in rocks of D_1 age near the head of Stockdale, close to the Middle Craven Fault, where it was first noticed by Prof. Marr (39, p. 343); but similar quartz-crystals are common in the limestone of the faulted region of the High Hills, nearer Settle. These also occur close to the North Craven Fault, above Great Stainforth Bridge, in beds of S_1 age. The crystals, however, are not entirely confined to the neighbourhood of faults. We find them, though less abundantly, in the base of the limestone north of the faults at Austwick Beck Head, in beds of S_2 age, and below Thornton Force in beds of C_2 age. All the examples occur near lines of weakness, either vertical faults, or the horizontal plane of the unconformity, where water containing silica in solution could circulate most easily and by impregnating the limestone along the margins produce metasomatic replacement. By far the richest development of the crystals is found in crushed regions in the neighbourhood of the North Craven Fault and the High Hills, where they are associated with a local development of dolomite (see Pl. XIX, figs. *5 a* & *5 b*); and, at first sight, it would appear natural to attribute their formation either directly or indirectly to the effects produced by earth-movements.

There is, however, one example of the occurrence of these crystals which makes us hesitate before adopting that view. In this case the quartz-crystals are embedded in the pebbles of one of the limestone-conglomerates, described in a previous section of this paper as occurring in the wedge-shaped strip of country between the Attermire Fault and the Middle Craven Fault, a little west of Stockdale Farm. The crystals here, though abundant, appear to be confined to the pebbles and entirely absent from the matrix (Pl. XIX, fig. 4). It might be suggested that the conglomerate was a crush-conglomerate, and that the silica had been introduced here also as the result of earth-movements; but a careful examination of the rock in the field and in hand-specimens does not bear

out this suggestion, and there appears to be no doubt that the conglomerate is a contemporaneous formation. Unless, then, appearances are deceptive, the crystals in the pebbles would seem to have been formed before the limestone was broken up and the fragments rounded into pebbles, and therefore that the crystals originated at the time of the consolidation of the original deposit. In discussing the formation of the crystals in the limestone at the head of Stockdale. Prof. Marr remarks:—

'The perfection of the crystals suggests a peculiar condition of matrix during the time of their formation, and seems to bear out the observations which I have made concerning the limestones of the knolls, that their crystallization was due to removal of pressure and that they were in a quasi-fluid state before their final consolidation.' (39, p. 343.)

Prof. Marr does not suggest any origin for the silica, but he evidently regards the crystals as due to secondary change, as a result of earth-movements subsequent to the formation of the limestone. Examples of quartz-crystals in limestone of Carboniferous and Devonian age have been cited from other localities. Thus Prof. W. J. Sollas has suggested that the crystals in the limestone of Caldon Low are due to the displacement of the silica of sponge-spicules by carbonate of lime and the subsequent crystallization of the freed silica; while Mr. E. B. Wethered, in describing the quartz-crystals from the Devonian limestone of Lummaton and Barton, considers that they have originated from the silica of decomposing silicates, apparently at the time of the original consolidation of the deposits.

Dr. H. H. Bemrose (1), in his paper on the occurrence of quartz-rock and quartzose limestone in Derbyshire, attributes the crystals to simple crystallization of silica out of a siliceous solution. With regard to the source of the silica, he considers that it may have been derived from siliceous organisms in the limestone, or more probably from deep-seated thermal waters containing silica in solution.

In the Settle district we do not find the quartz-crystals associated with sponge-remains or fragments of silicates; whereas in the cherty limestone, where sponge-remains do occur, we have seen no trace of bipyramidal quartz-crystals. As the chert is evidently contemporaneous, it seems fair to assume that the silica forming the quartz-crystals is of different origin, and probably secondary. On the whole, then, the quartz-crystals would appear to have originated in the same way as those described by Dr. Bemrose from Derbyshire, and to be due to solutions, containing silica, which have circulated freely along lines of weakness, especially in the regions where faulting and crushing are most in evidence.

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EXPLANATION OF PLATES X–XXI.

Plate X.

View of Settle looking east. The Middle Craven Fault (MF), the Attermire Fault (AF), and the 'High Hills' (HH) lie between. The distant bushes indicate Banks Nursery, where the line of the Attermire Fault is interrupted by the continuous outcrop of the *Nematophyllum-minus* Beds (NM). (See p. 220.)

Plate XI.

Fig. 1. Thornton Force, Ingleton, showing the *Michelinia* Zone (M) with Basement Conglomerate (B), resting unconformably on Ingletonian Slates. (See p. 191.)

2. Nodular coral-bed in the Lower *Dibunophyllum* Sub-zone; Meal Bank Quarry, Ingleton. (See p. 213.)

Plate XII.

Coal-seam (C) and mudstone in the Lower *Dibunophyllum* Limestone. A line of thrust (T) can be seen above the coal; Meal Bank Quarry, Ingleton. (See p. 214.)

Plate XIII.

Fig. 1. Thrust (T) in Meal Bank Quarry. South Craven Fault (F); Dolomite (D). (See p. 215.)

2. Thrust in the Lower *Dibunophyllum* Sub-zone, Storrs Common, Ingleton. The *Cyrtina* Band is here repeated, possibly in connexion with this thrust. (See p. 216.)

Plate XIV.

Fig. 1. View of the Middle Craven Fault (MF), from Malham, looking west towards Pikedaw. Lower *Dibunophyllum* Sub-zone with *Cyrtina* Band. Conglomerate at C. (See p. 225.)

2. 'High Hill' from the east, showing the junction of knoll-limestone (K) on the south with D_1 limestone on the north. A layer composed of dolomitized and silicified limestone forms the junction on the skyline. (See p. 244.)

Plate XV.

Fig. 1. Synclinal fold in cherty limestone underlying knoll-reef limestone, Haw Hill, Hanlith, near Malham. This fold forms a ridge on both sides of the Aire. (See p. 234.)

2. Lenticular 'eye' of crinoidal limestone above Lower *Lonsdalia* Beds, showing miniature knoll-structure intensified by pressure; Great Scar, above Stockdale Farm. Bryozoa Series (Br.); cherty *Lonsdalia* Bed (C.L.); crinoidal lenticle (Cr.). (See p. 224.)

Plate XVI.

[All the figures in Plates XVI–XVIII are of the natural size, unless otherwise stated.]

Figs. 1 *a* & 1 *b*. *Aulophyllum concentricum* sp. nov. Nodular Bed, Meal Bank Quarry, Ingleton. Horizon D_1. (See p. 259.)

Fig. 2. Another specimen from the same bed. (See p. 259.)

Figs. 3 *a* & 3 *b*. *Dibunophyllum aspidiophylloides* sp. nov. Nodular Bed, Meal Bank Quarry, Ingleton. Horizon D_1. (See p. 260.)

4 *a* & 4 *b*. *Dibunophyllum* sp., tending towards *Histiophyllum dicki* Thomson. Nodular Bed, Meal Bank Quarry, Ingleton. (See p. 260.)

5 *a* & 5 *b*. *Dibunophyllum vaughani* (= *Dibunophyllum* θ Vaughan). Nodular Bed, Meal Bank Quarry, Ingleton. Horizon D_1. (See p. 259.)

6 *a* & 6 *b*. *Dibunophyllum bristolense* (= *Dibunophyllum* ψ, early form, Vaughan). Nodular Bed, Meal Bank Quarry, Ingleton. Horizon D_1. (See p. 259.)

Plate XVII.

Figs. 1 *a* & 1 *b*. *Dibunophyllum* sp. aff. *matlockense* Sibly. Above Hunt Pot, Penyghent. Horizon D_2. (See p. 260.)

2 *a* & 2 *b*. *Dibunophyllum rhodophylloides* sp. nov. Old Ing, Penyghent. Horizon D_2. (See p. 261.)

3 *a*, 3 *b*, & 3 *c*. *Lophophyllum magnificum* (Thomson & Nicholson). Above Hunt Pot, Penyghent. Horizon D_2. (See p. 262.)

Fig. 4 *a*. *Rhodophyllum distans* sp. nov. Above Hunt Pot, Penyghent. Horizon D_2. (See p. 261.)

4 *b*. The same, longitudinal section, $\times$ 3/2. (See p. 261.)

Plate XVIII.

Fig. 1. *Productus pugilis* Phillips. Back Scar, east of Settle. Horizon D_2. (See p. 205.)

2. *Pemmatites* sp. $\times$3/2. Lamellibranch Bed, Fairweather Springs, Ingleborough. Horizon D_2. (See p. 204.)

3. *Rhodophyllum distans* sp. nov. Above Hunt Pot, Penyghent. Horizon D_2. (See p. 261.)

Figs. 4 *a* & 4 *b*. *Lithostrotion arachnoideum* (M'Coy). Scaleber Quarry. Horizon: chert-beds just below the knoll-reef limestone. (See p. 262.)

SETTLE, with the MIDDLE CRAVEN and ATTERMIRE FAULTS.

Fig. 1.—Thornton Force. Unconformity.

Fig. 2.—Meal Bank Quarry, Ingleton. Nodular Coral-Bed.

T.

Meal Bank Quarry, Ingleton. [Coal-seam (C) in D_1. Limestone showing thrust-plane (T).]

Fig. 1.—Meal Bank Quarry, Ingleton. Thrust.

Fig. 2.—Storrs Common, Ingleton. Repetition of *Cyrtina-septosa* Beds.

Fig. 1.—Middle Craven Fault, Malham.

M.F.

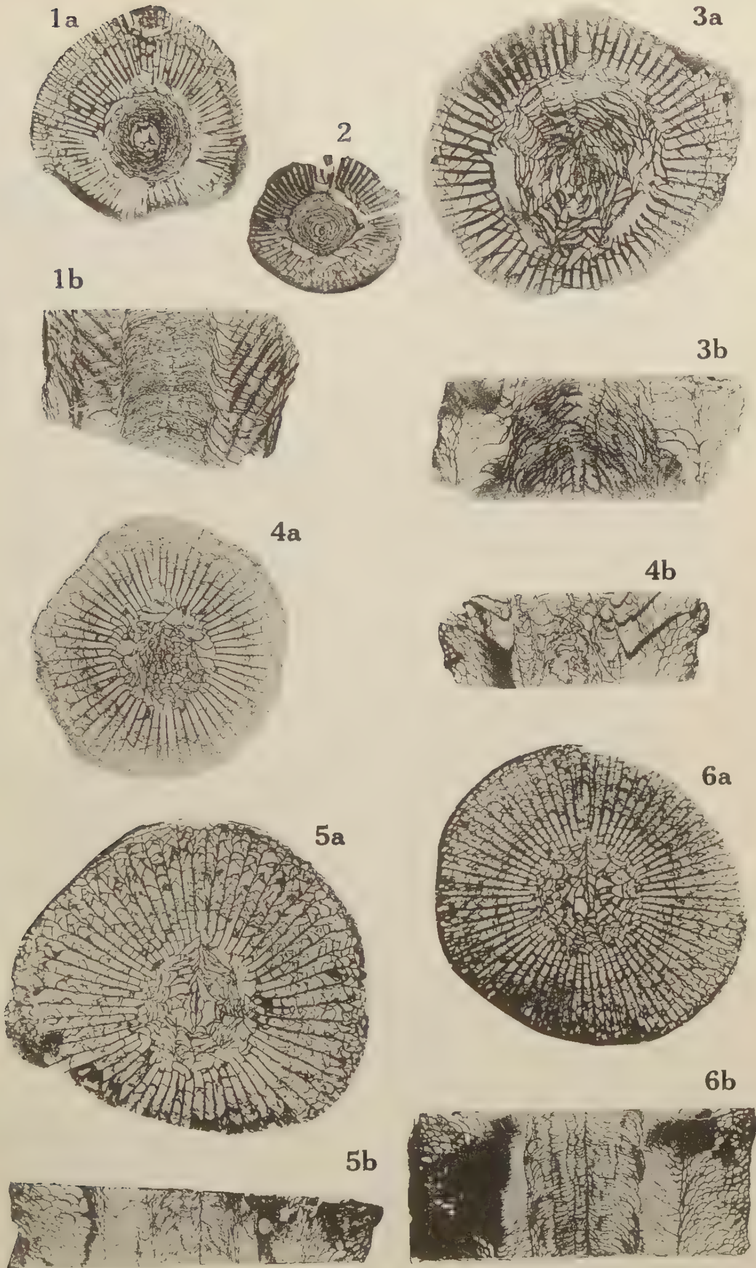
Fig. 2.—Junction of Knoll Limestone (K) and D_1 Limestone, High Hill, Settle.

Fig. 1.—SYNCLINE IN CHERTY LIMESTONE, HAW HILL, MALHAM.

Fig. 2.—KNOLL-STRUCTURE IN CRINOIDAL LIMESTONE D_2, GREAT SCAR, STOCKDALE.

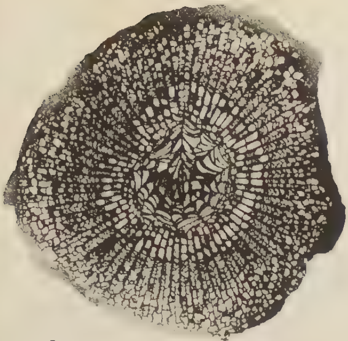
Cr.
C.L.

Br.

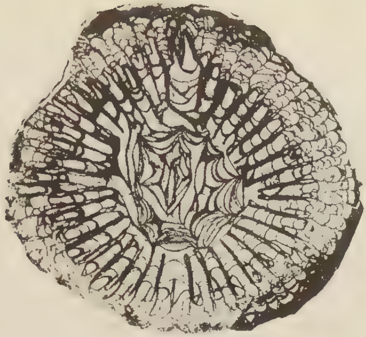


AULOPHYLLUM and DIBUNOPHYLLUM.

1a

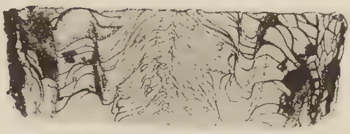


2a

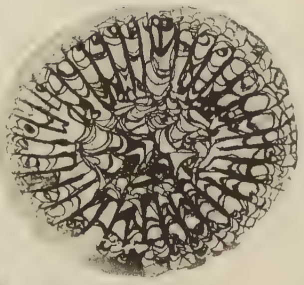


1b

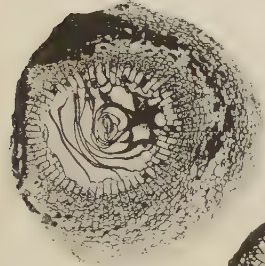
2b



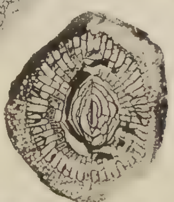
4a



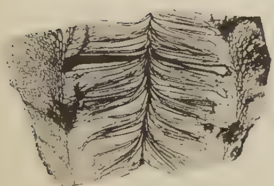
3a



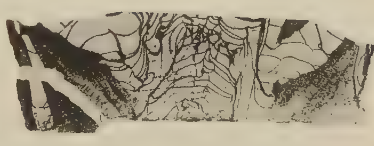
3b



3c

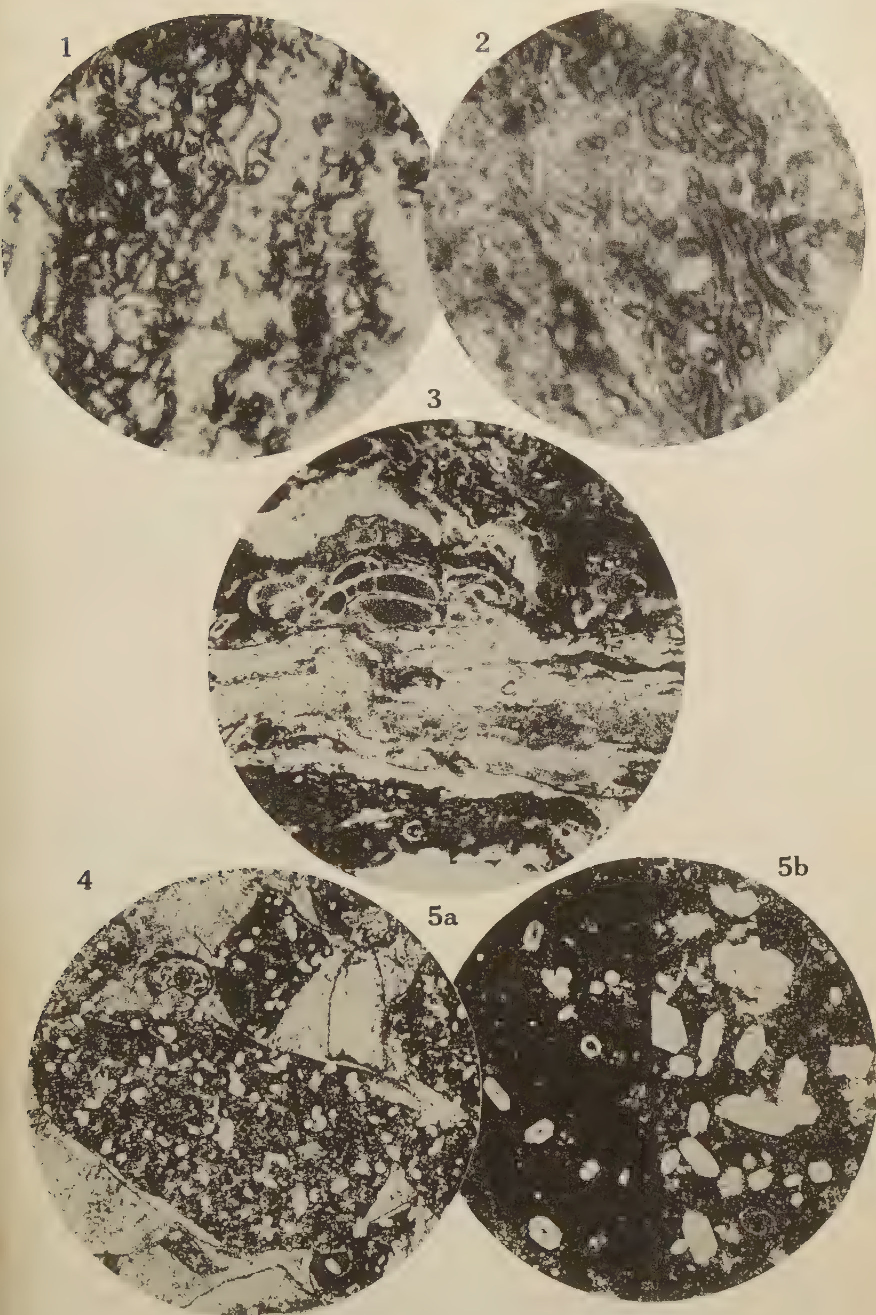


4b



DIBUNOPHYLLUM, LOPHOPHYLLUM, and RHODOPHYLLUM.

PRODUCTUS, PEMMATITES, RHODOPHYLLUM,
LITHOSTROTION, and ZAPHRENTIS.



GIRVANELLA, BEAN-SHAPED ORGANISMS,
and QUARTZ-CRYSTALS.

Fig. 5. *Zaphrentis nodosa* (Smyth). × 3/2. Goniatite-Bed, knoll-reef limestone, Stockdale Gorge, near Settle. (See p. 262.)

Figs. 6 *a* & 6 *b*. *Zaphrentis* sp. nov. 1. × 2. Keld Bank Sike, Ingleborough. Horizon D_2. (See p. 262.)

Fig. 7. *Zaphrentis* sp. nov. 2. × 2. Moor Close Gill, Bordley, east of Malham. Horizon D_2. (See p. 263.)

8. *Zaphrentis* sp. nov. 3. × 2. Gauber High Pasture, Ingleborough. Horizon D_2. (See p. 263.)

PLATE XIX.

Figs. 1 & 2. *Girvanella* sp. Small and large tubes. *Girvanella* Nodular Bed. Hunt Pot, Penyghent. × 100. (See p. 200.)

Fig. 3. Section of nodule, showing concentric layers of *Girvanella* (G), Calcite (C), and 'bean-shaped' organisms with an infilling of iron pyrites: these nodules are very characteristic of D_2. Fairweather Springs, Ingleborough. × 35. (See p. 203.)

4. Quartz-crystals in pebbles of limestone-conglomerate. Halsteads, east of Settle. × 35. (See p. 265.)

5 *a*. Quartz-crystals in limestone showing zoning. Great Knott, east of Malham. × 25. (See p. 265.)

5 *b*. Quartz-crystals in limestone showing zoning. Stockdale Beck Head, east of Settle. × 25. (See p. 265.)

PLATE XX.

Geological sketch-map of the Settle district, on the scale of 1 inch to the mile, or 1 : 63,360. This map shows the general zonal succession in the Lower Carboniferous rocks of the Settle District. The detailed outcrops in between the faults are only approximately correct. This district and that south of the faults are shown more accurately in Pl. XXI on a larger scale. The double lines in D_2 and D_3 representing the Yoredale limestone bands are taken from the 1-inch Geological Survey map. The highest of these represents the Main Limestone of the Survey map; the rest are almost devoid of fossils, and are of no zonal significance. The *Orionastræa* Band on Ingleborough represents the Hardraw Scar Limestone of the Survey, but reasons are given in the text for the conclusion that this horizon may represent the Simonstone Limestone of the Upper Wharfe district and of Wensleydale. A similar band with chert occurs in the lowest Yoredale limestone on Fountains Fell, but *Orionastræa* has not been found in it. The junction between S and D_1 must be considered in many places as approximate only when the Porcellanous Bed is not developed. This is notably the case in the district between the faults, as at Attermire Scar, Gordale Scar, and Malham Cove. The outcrop of the *Viviparus* Bed at Horton Limeworks is too small to map in accurately, and is now covered with débris from the quarry: it is approximately on the site of the water-tank. Detailed mapping has not been attempted east of the rivers Skirfare and Wharfe, but the faunal succession is normal here up to the *Orionastræa* Band, which has been traced to the east of Kettlewell.

PLATE XXI.

Geological map of the district between the Craven Faults in the neighbourhood of Settle, on the scale of 2 inches to the mile, or 1 : 31,680. This map shows the detailed outcrops of the beds between the faults and the general succession immediately south of the Middle Craven Fault. Patches of south-country rocks represented by knoll-reef limestone and Bowland Shales are shown to occur north of the Middle Craven Fault, near Settle and Bordley Hall. The areas left blank represent rocks of doubtful age.

Discussion.

Prof. J. E. Marr said that he had been over much of the ground with one of the Authors, and was convinced of the accuracy of their palæontological sequence. As a result of mapping by palæontological zones they had been able to interpret the complete fault-system of Craven, and he congratulated them on the importance of the results thus obtained.

He (the speaker) had certainly claimed that thrusting existed here, but supposed that the thrust was from the north. As the result of the Authors' work, however, he was convinced of his mistake, and that the thrust came, as they claimed, from the south.

He believed that the marked contrast between northern and southern facies was due to thrust against the rigid horst on the north, and that where that horst ceased westwards, the thrust rocks were free to move northwards and here, as stated long ago by McKenny Hughes, Carboniferous beds of intermediate type were formed near Kirkby Lonsdale. Farther west, the Lake-District horst, less resistant than that of the Pennines, caused the northern end of the thrust area to lie in a more southerly tract than in the Kirkby Lonsdale area. This region of thrust probably extended from the Lake-District border through the Isle of Man, and perhaps into Ireland.

He was glad that the work of the Authors gave additional support to the views which he had put forward concerning reef-knolls.

Prof. O. T. Jones suggested that, in order to avoid confusion in the use of the same expressions with quite different meanings, it would be advisable to utilize some other term than 'north country and south country' for the area on the north and south respectively of the Craven Faults.

With regard to the overthrust which the Authors had invoked, so as to explain the difference between the developments in these two areas, one would have expected to find evidence of overthrusting movements on a larger scale than that described by the Authors. It was difficult to reconcile the Authors' contention that the two facies were laid down some distance apart, and had been brought together by thrusting, with the relatively small movements along other parts of the faulted region, particularly towards Skipton. He further pointed out that, although it was not generally known, the difference between the facies in the Craven district is not restricted to that area, but (as A. H. Green observed) is characteristic also of the Derbyshire area, where the difference between the succession on the east side and on the west side is analogous to, though not identical with, that between the area north and the area south of the Craven Faults.

He was informed by Mr. J. Wilfrid Jackson (of the Manchester Museum), who was engaged in the comparison of the succession on the east and west sides of the Derbyshire massif, and who allowed him to use the information, that in Derbyshire the difference is

probably accounted for by a non-sequence. As a similar non-sequence had been described by the late Arthur Vaughan, Dr. A. Wilmore, and others in the area south of the Craven Faults, he wished to ask whether this explanation would not largely account for the different developments in the two parts of the Craven district.

Mr. G. W. Lamplugh asked whether it was to be understood that the Authors accepted R. H. Tiddeman's view that the limestone-knolls owed their structure in the main to original inequalities of deposition or consolidation, while considering also that the structure had been modified by later earth-movement. If so, their explanation would go far towards reconciling the divergent opinions regarding the knoll-structure, and seemed very reasonable. If the knolls were knots of hard rock of early consolidation, they could not fail to have a strong local effect upon the weaker strata surrounding them during any kind of earth-movement on a large scale, and even during the slighter movements due to differential shrinkage. The knoll-limestones which the speaker had studied in the Isle of Man showed the same combination of original and superimposed structures.

The Authors thanked those present for the cordial reception which had been given to the paper, and expressed their appreciation of the confirmatory statements made by Prof. J. E. Marr.

In reply to Prof. O. T. Jones, Prof. Garwood pointed out that it seemed impossible to attribute the presence of the 'knoll-reef' limestone at High Hill or the Bowland Shales at Bordley to a non-sequence in the North-Western Province facies.

According to Prof. Marr, the 'knoll-reef' limestone of Cracoe and Scaleber represented the Pendleside Limestone, and was the equivalent of the Upper Scar or Main Limestone of Ingleborough; while W. Hind & J. A. Howe considered the Pendleside Series as lying entirely above the Yoredales: so that, if a non-sequence is postulated at High Hill, the whole of the Yoredale Series is missing, and the 'knoll-reef' limestone is there brought against limestone of D_1 age. Again, at Bordley the Bowland Shales would also be overlapping on to the top of D_1. The whole character of the faulting and folding on the south pointed to movement in a northward direction against the rigid block. He regretted that, owing to the lateness of the hour, and in view of another paper to follow, he could not reply fully to the questions raised in the course of the discussion, but believed that all the points had been dealt with in the paper itself.

11. *The* Development *of the* Severn Valley *in the* Neighbourhood *of* Iron-Bridge *and* Bridgnorth.

By Leonard Johnston Wills, M.A., Ph.D., F.G.S.; with a *section on the* Upper Worfe Valley, *in collaboration with* Ernest Edward Leslie Dixon, B.Sc., F.G.S. (Read November 21st, 1923.)

[Plates XXII & XXIII—Map & Sections.]

Contents.

I. Introduction.

The late Prof. Charles Lapworth inspired me with a desire to test the validity of his hypothesis, put forward as long ago as 1898,[1] that the Upper Severn was added to the Lower Severn as a result of the impounding of a glacial lake in Shropshire and Cheshire. The lake, according to the hypothesis, rose until it flowed out over the former watershed between the Shropshire plain (which originally had drained to the Dee or the Mersey) and the headwaters of a tributary of the Worcestershire Stour.

The same view was put forward independently by F. W. Harmer in 1907,[2] in a paper accompanied by an excellent contoured map, which may be conveniently consulted in connexion with the present work.

Neither Lapworth nor Harmer attempted, so far as I know, to bring forward detailed evidence in support of the hypothesis.

[1] Proc. Geol. Assoc. vol. xv (1898) p. 425.
[2] Q. J. G. S. vol. lxiii (1907) pp. 477–81.

Lapworth called attention to the rejuvenation of the Severn and its tributaries, which he regarded as resulting from the diversion, into a diminutive tributary of the Stour, of the copious waters of the Upper Severn which had originally flowed into the Dee; while Harmer pointed out the existence of Glacial lake-deposits on the Shropshire Plain.

Harmer threw out the suggestion (*op. cit.* p. 479) that the Severn Valley from Bridgnorth to Bewdley was initiated as a marginal drainage-channel on the west side of the ice-lobe that left so many Scottish and Lake-District boulders around Wolverhampton and Bridgnorth.

II. Statement of the Problem.

As may be seen from any contoured map, the Cheshire-North Shropshire Plain is surrounded by higher ground on the west, south, and east, with the exception of the gorge at Iron-Bridge. Were the drifts cleared out of the plains, this relief would be considerably accentuated.

The ring of high ground shows signs at Rudyard and elsewhere of having had drainage-channels excavated across it,[1] a fact that increases the probability that the Iron-Bridge gorge arose as such an overflow-channel. But the gorge does not cut across the ancient watershed at the point where it was lowest: that is, in the neighbourhood of Newport (Salop). Harmer assumes that this lower col could not be used, inasmuch as it was overspread by the ice-sheet that impounded the Shropshire Lake, and perhaps by Pennine ice. Mr. E. E. L. Dixon's preliminary statement[2] regarding the Newport district confirms this view.

I set about examining the district in the spring of 1914, with the conviction that the mapping of the glacial, fluvio-glacial, and river-deposits should give a very direct answer to the question as to whether Lapworth's and Harmer's hypothesis was correct; and, if so, as to the sequence of events that led the Severn to flow in the Iron-Bridge Gorge.

The descriptions of the drifts of this district given by Maw, Mackintosh, and others,[3] lose some of their value, in that they are coloured by the then-current views of glaciology held by the writers. In order to avoid, in some degree, falling into the same error, I have tried in the sequel to separate so far as possible my data from the theories that they suggest to my mind.

[1] See F. W. Harmer, *op. cit.*, for references.

[2] 'Summary of Progress for 1920' Mem. Geol. Surv. 1921, p. 20.

[3] G. Maw, Q. J. G. S. vol. xx (1864) p. 133; D. Mackintosh, *ibid.* vol. xxix (1873) pp. 358–59 & vol. xxxv (1879) p. 436; J. Carville Lewis, 'The Glacial Geology of Great Britain & Ireland' 1894.

III. The Topography of the Iron-Bridge, Shifnal, and Bridgnorth District.

The following units may be recognized:—

1. The Buildwas Strath.
2. The Barrow-Broseley and the Madeley-Shifnal Plateaux.
3. The Iron-Bridge–Bridgnorth Gorge.
4. The Worfe Vale.

(1) The Buildwas Strath is a continuation eastwards of the Shropshire Plain, and is a fairly open valley through which, in the west, the Severn meanders on a broad flood-plain (gradient = 1·66 feet per mile). Eastwards, the valley and the flood-plain contract towards the entrance of the Iron-Bridge Gorge, at which point Coalbrookdale debouches. The latter may be regarded as the natural continuation of the Buildwas Strath.

(2) The Barrow-Broseley and the Madeley-Shifnal Plateaux.—A high plateau with a north-westward facing scarp, extends from near Much Wenlock, through Barrow, and along Benthall Edge, to Iron-Bridge. Southwards, the plateau is continued through the high ground of Shirlett Common, Willey, and Tasley, to the valley of the Mor Brook. North of the Iron-Bridge Gorge a similar plateau stretches from Coalbrookdale and the Wrekin towards Madeley and Shifnal, and is prolonged northeastwards as the divide at the head of the Worfe Valley. The two plateaux, although separated by the Severn Valley, form a single unit. They both slope, in the main, towards the low ground of the Worfe Valley. They are both seamed by small brooks having a general south-easterly direction, of which we may note from north to south, the Wesley Brook (upper part), the Hem Brook, the Mad Brook (lower part), the Coalport Brook (upper part), the Horsehay Brook (upper part), the Dean Brook, the Linley Brook (upper part), the Mor Brook, and others farther south and outside the district. These brooks may be regarded as consequent streams related to the general dip of the older rocks. The valleys of the Worfe and of the Severn, south of Apley, are parallel to the strike of the Trias.

Two major watersheds (Pl. XXII) occur on the plateaux:—First, that from Henmoor Hill to the Barrow Col (see below) and thence along the crest of the Barrow-Broseley Plateau to Iron-Bridge, and from Iron-Bridge to Lightmoor and Dawley. These separate the drainage reaching the Severn, west of the Iron-Bridge Gorge, from that which flows directly to the gorge or to the Worfe. Secondly, the divide running from the Wrekin, eastwards through Dawley and Oakengates, to Weston Heath and Weston-under-Lizard. This separates the tributaries of the Tern and the Meese from those of the Worfe. The major divides are referred to in the sequel as 'the watershed': in pre-Glacial times it was unbroken at Iron-Bridge.

A secondary divide runs southwards from the Barrow Col between the Mor Brook drainage-basin and the other western tributaries of the Severn.

The crest of the plateaux sags in places to cols, of which the following may be noted. They are indicated by letters on the map (Pl. XXII):—B, the Barrow Col, 630 feet O.D.; P, the Posenhall Col, 595 feet O.D.; L, the Lightmoor Col, 365 feet O.D.: all these cross the first divide. C, the Coalmoor Col, 632 feet O.D.; O, the Oakengates Col, 470 feet O.D.; and G.B., the Gorsey Bank Col, 350 feet O.D., traverse the second.

(3) The Iron-Bridge–Bridgnorth Gorge.—Diagonally across the sloping plateau runs the trench-like gorge of the Severn (gradient: Iron-Bridge to Bridgnorth=3·3 feet per mile; Bridgnorth to Hampton Loade = 2 feet per mile). From Iron-Bridge to Swinney its direction is from north-west to south-east, parallel to the consequent brooks; from Swinney to Bridgnorth it is almost north to south, parallel to the strike of the rocks. Its sides are so steep that in many places landslips have occurred, and are still proceeding, as may be especially well seen at Madeley Wood, near Coalport (Pl. XXII, M). The small tributaries which the gorge receives have very steep gradients, and some are hanging valleys.

(4) The Worfe Valley.—The Worfe and its tributaries occupy an open, gently undulating vale, some 3 or 4 miles across. Its direction is from the north, southwards almost to the latitude of Bridgnorth. The streams lie for the greater part deeply incised below the general level of the country. The Worfe eventually passes in a shallow gorge through the Pebble-Bed Escarpment into the Severn, about 2 miles north of Bridgnorth. For the present purpose, the most important tributary of the Worfe is the Mad Brook which, rising near Stirchley, flows past Cuckoo Oak, south-eastwards to the Worfe at Beckbury.

IV. The Glacial Deposits.

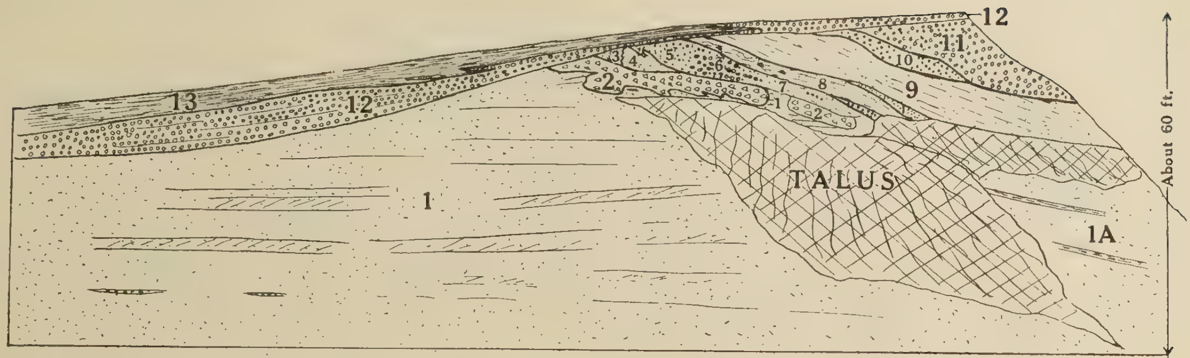
The drifts of the whole district are almost exclusively derived from the Irish Sea Glacier, being full of granite-boulders from the Lake District and the South of Scotland. There is a large admixture, however, of Welsh material, much of it in the form of shingle. It is possible that this may have been derived from earlier glacial deposits, and not directly from Wales. Evidences of such deposits are dealt with on pp. 287, 291, & 292.

(A) Environs of Iron-Bridge.

The Severn Valley, from Buildwas to the mouth of Coalbrookdale, contains large mound-shaped hillocks of clean sand and gravel, which may be termed the Buildwas Sands. The most conspicuous mounds are grouped in the narrowing eastern end of the Strath. Maw gave a good description of one of these at

Fig. 1.—*Section in the pit by the railway, near Buildwas Abbey.*

[Length of section=about 130 yards.]



1=Sharp brownish sand, with small chips of slate, shell-crumbs, and occasional small seams of shingle. The false bedding dips eastwards.

1 A=Clayey sand, with silt layers. (Possibly distinct from 1.)

2. Blocks of tough grey-brown boulder-clay, with shell fragments and many fairly local boulders. Sand disturbed below the biggest block, which was 16 yards long and 5 feet deep.

3. Distorted clayey sand.

4. Unbedded sand.

5. Shingle, passing, along an almost vertical line, into

6. Coarse gravel, which grades into

7. Silty sand, with seams of shingle.

8. Irregularly bedded clayey silts, with odd boulders and seams of sand and shingle.

9. Sands, silty clays, and thin beds of stony clay. Dips fairly steeply westwards.

10. Shingle and fine gravel.

11. Unbedded gravel.

12. Coarse bedded gravel, with blocks measuring up to $2\frac{1}{2}$ feet in diameter near its base. Dips eastwards.

13. Grey silts and sands.

Strethill (Pl. XXII, Q), as long ago as 1864. He made an important point in showing that the sands descend to the bottom of the valley, that the mounds rise to about 300 feet O.D., and that the internal structure bears no relationship to the present shape of the hill.

At Strethill the railway-cutting and gravel-pit in those days showed two masses of clean sand and gravel, separated by about 60 feet of an heterogeneous clayey gravel and clay-deposit; this was evidently of the nature of boulder-clay, and contained lumps of Wenlock Shale and more angular boulders than the sands. Only part of the upper sands and gravels is now exposed.[1]

There are at the present time fine sections open near Buildwas, especially in the pit at the side of the railway near Buildwas Abbey. The section (fig. 1, p. 278) is based on observations made in 1920 and 1923. The most striking feature, apart from the great mass of sharp clean sand, with shell-fragments and tiny bits of slate, was provided by the large blocks of tough grey boulder-clay containing stones and marine shells. The horizon in which the blocks of boulder-clay occur is succeeded by gravels, sands, and silts having a rather steep dip. The blocks appear to have been deposited from floating ice, and to have ploughed up the underlying sands, which are disturbed and cut off by the clays and silts. In the pit by the railway-station no boulder-clay occurs. It was this pit to which Maw's observations refer.

He collected a number of marine shells at Strethill, and fragments occur in the sands and boulder-clay at Buildwas Abbey; but, as such shells are habitually found in deposits laid down by the Irish Sea Glacier, they are now usually, and (I think) correctly, regarded as boulders, not as indications of a submergence.

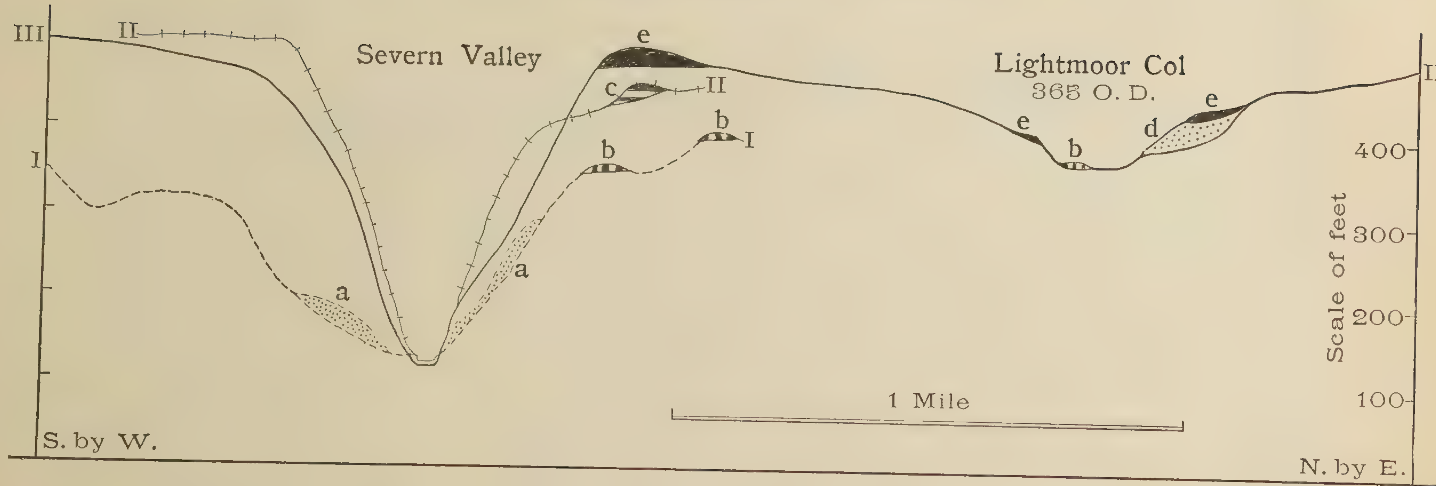
A gravel overlies the other deposits at Buildwas Abbey. It resembles river-gravel, and is interbedded with silts. At the south-western end (not shown in the section) other gravels occur that are probably connected with the Farley Brook.

Immediately east of the mouth of Coalbrookdale, the Severn enters the Iron-Bridge Gorge, which presents every appearance of a recent origin. The river falls fleetly over the rapids, the valley sides are steep, and ever on the move, both large and small landslips being conspicuous. The tributaries descend in ravines from the high plateau that in many places extends to the brink of the gorge. No glacial and very little fluviatile drift is found in the upper part of the gorge, with the exception of a small patch of gravels near Swinney.

On the plateau, however, there are fairly large spreads of boulder-clay at about 440 to 500 feet O.D. near Madeley Wood Colliery (Pl. XXII, M). The deposit, 12 feet thick, is typical brownish till, with plentiful boulders in it. Only a very few of these are

[1] G. Maw, Q. J. G. S. vol. xx (1864) p. 133 & fig. 1.

Fig. 2.—*Sections transverse to the Severn Valley.*



I. Across the Buildwas Valley, near Buildwas Junction and Strethill Farm (Pl. XXII, Q): a=the Buildwas Sands; b=gravelly clay.

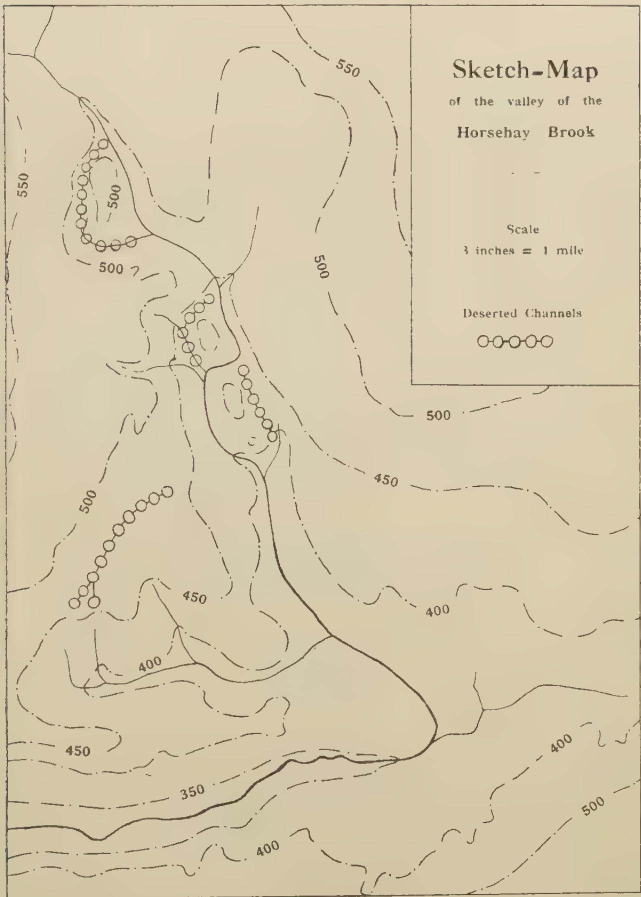
II. At Lincoln Hill: c=the Lincoln Hill Silts.

III. Through Madeley Wood and Lightmoor: b=clayey gravel: d=the Lightmoor Sands; e=boulder-clay.

far-travelled, the bulk being Coal-Measure material. The upper part of the deposit is more sandy and roughly bedded. This deposit was clearly laid down as ground-moraine when no gorge existed, see sections (fig. 2, p. 280).

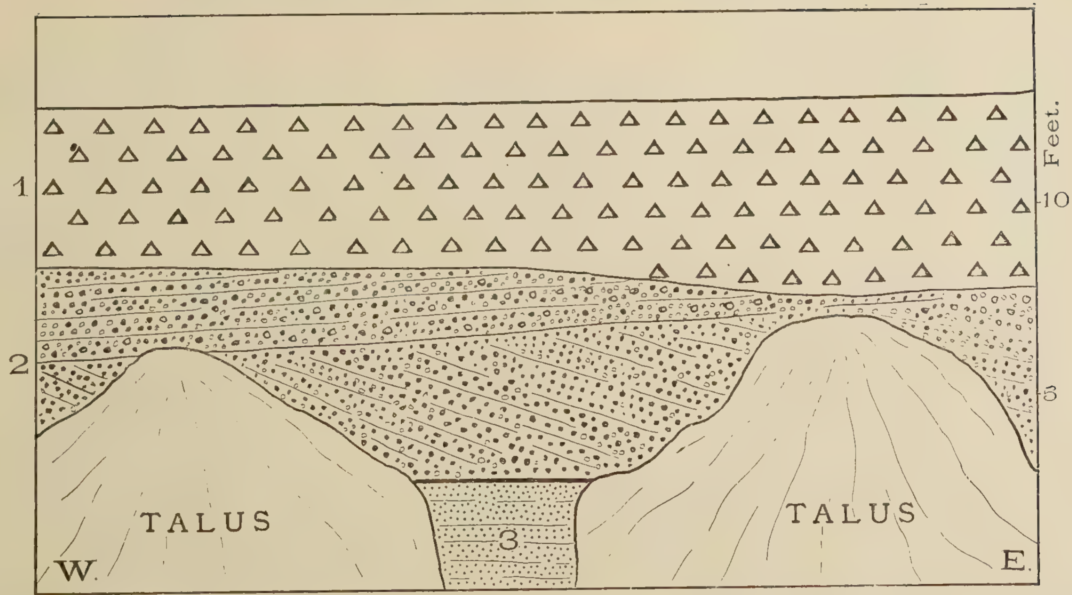
Maw records drift from Benthall, Posenhall, and Broseley on the plateau south of the gorge; but exposures are rare, and it is possible that he only refers to boulders (*op. cit.* p. 132).

Fig. 3.—*Sketch-map of the valley of the Horsehay Brook, on the scale of 3 inches to the mile, or 1 : 21,120.*



At about 450 to 460 feet O.D., on the very crest of the valley-side at Lincoln Hill, Iron-Bridge (Pl. XXII, LH, & fig. 2) occur 12 feet of laminated clay, fine silts, bedded clay, and

Fig. 4.—*Sand-pit, Hill Lane, Cuckoo Oak, Madeley.*



1 = Boulder-clay. 2 = False-bedded fine shingle and sand, with erratic pebbles, coal, and shell-fragments.
3 = Horizontally bedded sand.

laminated silts, with occasional erratics of small size in the uppermost 3 feet. These are dug for a moulding-sand ingredient at a point 150 yards west of Madeley Union Workhouse.

These silts present the appearance of lake-deposits, but could only have come into existence in a lake in this position and at this level when an ice-dam or watershed higher than 460 feet O.D. lay across the present site of the Iron-Bridge Gorge. Against such a watershed (and we see indications of its existence in the high drift-covered plateau just described) a glacier-lake might have been impounded by ice occupying the Buildwas Strath.

The Horsehay Brook, which is the eastern feeder of the Coalbrookdale stream, is of particular importance in the history of the district (see fig. 3, p. 281). It rises on the Tern-Severn watershed at the Coalmoor Col (Pl. XXII, C). From its source to Lightmoor Station it flows on solid rocks, that are in places capped by thin spreads of boulder-clay; but its valley is remarkable, on account of the curious abandoned courses (fig. 3).

At Lightmoor Station [1] it takes an acute bend; the character of the valley changes, and the stream begins to drop more rapidly to Coalbrookdale, at one place being cut in boulder-clay. This lower part has an east-and-west alignment, and is continued eastwards by the wide, fairly flat-bottomed through-valley of the Lightmoor Col (Pl. XXII, L & fig. 2, p. 280).

This through-valley has clearly been excavated by water flowing across what is now a major watershed. Its northern flank has been cut out of thick drifts; while on its southern side, boulder-clay probably caps a steep bank of Coal Measures. The following section was exposed near the triangulation-point 441 O.D., behind Moor Farm, in 1923:—

	Thickness in feet.
Reddish stony boulder-clay, with northern erratics	3
Grey boulder-clay, with boulders of Coal-Measure sandstone and shale, but no far-travelled erratics	5
Loamy red sand	5
Fine laminated silts	$2\frac{1}{2}$ to 3
Sand, with coal-pebbles, and fine gravel	3
Sharp reddish sand, with bits of coal and slate, like the Buildwas Sands	9+
	28

The sands and boulder-clay can be traced down the eastern end of the gap into the Madeley Court valley, and so past Cuckoo Oak into the valley of the Mad Brook.

The section of the sand-pit, in the abandoned Hill Lane Colliery, at Cuckoo Oak, is given in fig. 4, p. 282. Here typical till, with far-travelled erratics from Scotland, the Lake District, and possibly Wales, overlies shingly false-bedded gravel that in turn covers

[1] This part of the valley is almost obliterated by slag-heaps and pit-mounds.

horizontally-bedded sands. At the southern end of the pit. about 8 feet of boulder-clay overlie some 12 feet of sharp sand, with an occasional seam of shingle. The sand is like the Buildwas Sands.

Reverting to the Lightmoor Gap, I must point out that on its floor there are at least two low mounds of gravelly material that might be regarded as very stony boulder-clay (fig. 2, p. 280). Similar material is found at a few places (indicated by vertical striping on Pl. XXII, X & Y) on the higher parts of the valley-sides of Coalbrookdale.

The geological features of the vicinity of Lightmoor suggest the deposition of sands and shingle in water, possibly as an outwash-fan in front of, or between, two lobes of the ice-sheet; the over-riding of the sands by the ice-sheet that left the boulder-clay; the erosion of the through-valley by the waters of an overflow channel; and, finally, the possible occupation of the through-valley by ice that laid down the gravelly clay in mounds.

(B) The Worfe Vale and the Severn Valley South of Coalport.

The following varieties of drift may be distinguished:—

(1) Fairly stony, sandy till	True ground-moraine.
(2) Rather stoneless sandy clay and sand	Probably the finer outwash material.
(3) Kame-like mounds of gravel	Probably marginal deposits, presumably recessional.
(4) Fluvio-glacial[1] valley-gravels	(*a*) of the Dean & Linley Brooks;
	(*b*) of the Mor Brook;
	(*c*) of the Mad Brook and Lower Worfe.
(5) River-gravels and alluvium	(*d*) of the Severn;
	(*e*) of the Upper Worfe and Tong Brooks.

(1) Fairly stony till that may be regarded as ground-moraine occurs, as already noted, near Cuckoo Oak, and extends for a short distance down the Mad Brook. Similar clay occurs east and north-east of Shifnal. South of these two areas little can be said of the clayey drifts in the Worfe Vale, for they are poorly exposed. It is probable that true ground-moraine may occur at Echoes Hill Clay-Pit (Pl. XXII, E); perhaps near Norton and Apley Park Farm; near Crowgreaves; south-west of Merecot; near Alscot and Catstree. In the two last-named areas the material is very gravelly. At the Echoes Hill Pit, the clay exposed at present is almost stoneless; but, if we may judge from the bricks made there, it probably contains limestone-pebbles.

In the Severn Valley itself boulder-clay is rarely found south of Coalport. Isolated boulders, and possibly boulder-clay,[2] occur on

[1] See note on p. 289.
[2] G. Maw, Q. J. G. S. vol. xx (1864) p. 132.

the high ground near Broseley, Posenhall, and Barrow, up to about 700 feet O.D.

Mr. T. Robertson has pointed out to me one large and other smaller patches of sandy drift-clay near Colemore Green, a mile south-west of Apley, at elevations from about 250 to 300 feet O.D.

Big boulders of granite are found up to 400 feet O.D., west of Bridgnorth.

South of Bridgnorth, boulders (usually granites) are common round Eardington. In the railway-cutting between this village and Knowlesands (fig. 6, p. 292) a reddish sandy clay, with small erratics of the usual northern types, is seen to overlie the sands to which reference is made on p. 294. The big boulders at Eardington may be the relics of this deposit.

At about 270 feet O.D., 200 yards south by east of Potseething Farm, on the sides of a small tributary of the Severn, 4 to 5 feet of clay with scattered small stones, overlie about the same thickness of roughly stratified sand, with very thin clayey seams. There are coal-fragments in the sand, as is usually the case in this district.

A large boulder at about 240 feet O.D., and about a mile north of Hampton Loade, forms the southernmost occurrence of northern erratics so far observed on the west side of the Severn (excepting those in the terrace-gravels).

East of the river, Mackintosh and Harmer[1] record an abundance of boulders east of Bridgnorth. There is also a great accumulation of them at Mose, which is a farm lying about a mile south-east of Quatford. The boulders here appear to come from a clay-deposit that must (I think) be classed as boulder-clay; but there is no good section. They number some hundreds, and range up to 4½ feet in diameter. This occurrence is also mentioned by Mackintosh (*op. cit.* 1879, p. 437).

The foregoing records of boulders have been adduced, as they establish a minimum distance to which the northern ice extended. I cannot at present assert more than this, as I have not examined the country lying away from the main valley, west and south of the Mor Brook, Dudmaston Hall, and Quatt.

(2) South of the Mad Brook, and also near Evelith and Hinnington, are large areas of sandy clay, which southwards may pass laterally into sands. There are very few exposures, but the soils are slightly clayey, pebbly sands. The surface of these drifts is very level, and drops gradually with the valley.

There are several places where the clays and sands can be shown to overlie the fluvio-glacial gravels (4*c*), p. 290, of the Wesley Brook, the Mad Brook, and Lower Worfe Valleys; but the best exposure is in a pit three-quarters of a mile south by west of Beckbury (Pl. XXII, H). Here an unbedded, reddish sandy clay, with a few small erratics, is exposed to a depth of 5 or 6 feet.

[1] D. Mackintosh, Q. J. G. S. vol. xxxv (1879) p. 437; F. W. Harmer, *ibid.* vol. lxiii (1907) p. 479.

It presents the appearance of a true till, and clearly overlies 10 feet of fine gravel and shingle composed of slaty pebbles and northern erratics, with fragments of marine shells: a typical example of the Worfe Valley fluvioglacial gravels.

About three-quarters of a mile north-west of this locality, and near Cotsbrook, Higford, as also at and near Harrington Hall, sandy clay, sometimes with stones in it, overlies shingle and gravel of the same type.

The stretch of clay near Shifnal, Evelith Mill, and Hinnington is probably of a similar nature. In the road-cutting at Evelith Mill a rather stoneless clay is seen to overlie gravel and shingle. The clay here forms a very level surface. Farther up the Wesley Brook, near the Old Manor House, south of Shifnal, about 2 feet of tough red clay overlie several feet of sand and shingle.

Farther south, in the Worfe Valley, near Stableford and Cranmere Farm, sands appear to take the place of the clays, and to overlie the gravels.

At one time, I regarded the clays, described above, as ground-moraine, on account of their resemblance to till. This view makes the fluvioglacial gravels of the Worfe antedate the advance of the ice; but the distribution of the clays and of the gravels seems to suggest that the two deposits are intimately connected, and probably deposited in part contemporaneously. Some of the clay near the valley-sides may be a kind of wash from the higher ground; but much of the flatter parts may be regarded as flood-plain deposits of the waters that laid down the gravels in the actual river-channel. This view was suggested to me by Mr. T. Robertson, and would seem to explain many of the difficulties associated with the great flat spreads of exposureless clay that give to the Worfe Vale its peculiar configuration.

It is more than likely that the clays are lacustrine in part, for the glacial floods may at times have produced a lake in this flat and open valley, the waters of which could only escape by the narrow gorge into the Severn.

(3) Gravel-mounds:—(*a*) at low altitudes in the Worfe Valley.—Small, more or less, mound-like patches of gravel and shingle occur at and near Echoes Hill, south-east of Stockton (Pl. XXII, E); at Merecot; on both sides of the Shifnal Brook at Grindle (Pl. XXII, G), and near Evelith. Such gravels must, in my opinion, be regarded as glacial gravels of the nature of glacieluvial kames. In the case of the Echoes Hill deposit, the gravels show false-bedding that tends to dip towards the high Bunter Pebble-Bed ridge, as if they had been shot off the edge of the ice-sheet into water held up between the ridge and the ice. In composition, this gravel closely resembles the fluvioglacial valley-gravels, shortly to be described. In the other localities no exposures exist. Possibly these mounds may eventually help us to locate halting-places in the retreat of the ice.

(*b*) At high altitudes on the Broseley Plateau.—A large mound of gravel, pointed out to me by Prof. P. G. H. Boswell, occurs near Wyke (Pl. XXII, W), about a quarter of a mile west of Benthall Church. Its summit rises to 620 feet O.D. Its position west of and near the Posenhall Col (P), on the watershed of the Broseley plateau, suggests that it was formed at the ice-margin, at the time when the glacier-edge west of the watershed may have impounded a lake, the overflow of which poured across the col (see p. 303).

Two similar, though smaller mounds, rise to about the same level south of Posenhall, and may have originated at about the same time as marginal kames, when the ice-front lay along the southern flank of the Dean Brook Valley. A kame-like ridge of northern gravel occurs in Willey Park, near the Hangster's Gate.

Somewhat different in composition, shape and position, although probably formed at the same time as the Posenhall kames, is the deposit north-north-east of Dean Corner, in Willey Park, and adjoining the south side of the Barrow-Broseley Road (Pl. XXII, D & fig. 5, p. 288). Its shape is more terrace-like and less moundy than the Posenhall kames; but it is thoroughly morainic in its lower part (8 feet), containing boulders measuring as much as 3 feet in diameter. The majority of the stones are from local sources in the Coal Measures, but Eskdale granites, Uriconian felsites, Llandovery and Wenlock limestones are common; and Mr. J. Gray [1] records fragments of marine shells. The upper part of the deposit is roughly-bedded shingle, clean sand, and (in places) clayey sand.

This deposit may be partly glacial and partly fluvioglacial (see note, p. 289) in origin. In the latter respect, it may be correlated with terrace-like deposits near the mouth of the Dean and Linley Brooks (see p. 289).

An unique deposit occurs immediately south of Rhodes Farm, about a mile south-west of Nordley (see p. 293).

	Thickness in feet.
Clayey sand ...	3
Gravel of cornstone pellets ...	1
Sharp sand ...	2[2]
Gravel, with angular blocks of sandstone, nearly horizontal ...	2
Coarse and fine morainic gravel: the bigger blocks being mostly sandstone, calcareous sandstone, and occasional cornstone, the finer material mostly calcareous pellets derived from cornstones. The false bedding dips steeply southwards ...	7 +

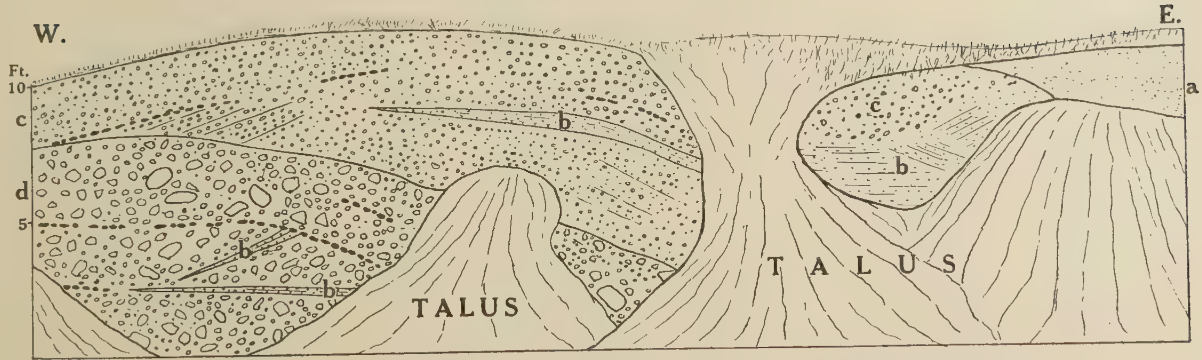
No far-travelled stones were found in the morainic gravel, but in the sand a few small pebbles of slaty rocks, possibly of Welsh origin, were noted. The top of the deposit reaches to about 385 to 390 feet, while the base is about 360 feet O.D.

The composition of this gravel shows it to be of local origin and

[1] Proc. Worcester Nat. Field-Club, 1914, p. 80.

[2] Not well exposed; but the thicknesses and sequence were obtained from the farmer.

Fig. 5.—*Gravel-and-sand-pit, Dean Corner, Willey Park, near Broseley.*



a=Clayey sands. b=Sharp sand. c=Fairly fine gravel or shingle. d=Coarse morainic gravel.

[The thick black dots indicate bands of decomposing ironstone-nodules.]

is strongly contrasted with the nearest patch of drift, which forms a low ridge, east of Houghton, composed of gravel with the typical assemblage of northern erratics. The Houghton gravels lie at a slightly lower level (namely, about 345 feet O.D.), and are connected in origin with those near Morville (see below).

(4) Fluvioglacial gravel[1]: (*a*) the Dean and Linley Brooks.—These gravels occur near where the present streams join the Severn. They lie at about 295 to 320 feet O.D. (that is, about 200 feet above the present river), although their height above the brooks is by no means so great, on account of the steep gradients of the latter. The general agreement in height and, in the Linley Brook Valley at any rate, their obvious origin as torrential flood-gravels confined by the then valley-sides, give some idea of the former altitude of the valley-floor in what is now the Severn Gorge. The amount of subsequent denudation is enormous.

The gravel, where coarse, contains blocks measuring as much as $2\frac{1}{2}$ feet in diameter, of more or less local derivation, and smaller far-travelled stones, of which Eskdale granites are the most easily identified. The finer material is mostly shingle; but there are seams of sharp sand, with the usual coal-pebbles. The whole is false-bedded where well exposed, in the pit a quarter of a mile south of Hem. The dip of the false bedding is in the opposite direction to the fall of the present valley.

Immediately north of 'The Hollybush,' on the south side of the valley, similar erratic gravel overlies a truly morainic deposit, in which the large blocks are mostly of more or less local origin: *Spirorbis* Limestone, coal and ironstone, Ludlow, Old Red, and Carboniferous sandstones; but there are also a few granites and other igneous erratics.

(*b*) The Morville gravels.—The Mor Brook reaches the Severn by a deep gorge; but, above Harpswood Bridge, it and its tributary, the Tiddle Brook, occupy an open valley.

The Morville gravels and sands are found here partly as mounds (especially just west of Morville Heath), and partly as rough terraces at various levels on both sides of the tributary valley that runs through Morville. In places they descend almost to the bottom of the valley, while their summits rise to about 370 feet O.D. near Morville; but a second terrace-like spread, above which low mounds rise in places, occurs near Bridgwalton, at a general level of about 275 to 290 feet.

A dominant brown colour and abundance of northern erratics characterize the gravels and sands. The best exposure is in a gravel-pit, a quarter of a mile north-east of Morville. Here a nearly complete sequence can be studied in two adjoining pits.

[1] The term fluvioglacial is here applied to deposits laid down by melt-waters away from the actual ice-front.

Upper Pit.

	Thickness in feet.
Coarse, almost unbedded gravel, with seams of brown, fairly sharp sand	6

Lower Pit.

Coarse gravel, with blocks up to 2 feet in diameter	3 to 4
Lenticle of sand, with scattered pebbles	0 to $2\frac{1}{2}$
Fine, rather muddy gravel	$1\frac{1}{2}$ to $3\frac{1}{2}$

The following boulders were noted:—Pink granite (? Eskdale), Scottish grey granite (common), analcite-basalt,[1] Wenlock and Llandovery Limestone, numerous sandstones derived from the Old Red Sandstone and probably from the Carboniferous, coal (fairly common), ironstone, volcanic grits, ? Uriconian felsite, and chert.

A rather overgrown pit, alongside the main road, three-quarters of a mile north-west of Morville, shows that the deposit is here about 40 feet thick, and is, with the exception of a stony wash on the top, devoid of gravel. Brown loamy sands and dull brown-red sharp sand occur in the upper part; while sharp reddish sand with small slate-fragments and shell-crumbs can be seen near the base. The latter sand resembles those of Buildwas and Cuckoo Oak. The shape of the ground suggests that the bank in which the pit occurs is the original westward termination. It will be shown in the sequel (p. 301) that these sands were probably deposited in a lake.

Tough drift-clay occurs at Morville Heath, where holes got out for foundations showed:—

Red clay	2 to $2\frac{1}{2}$ feet.
Brown clayey sand with erratics, including granites and volcanic ashes (? Welsh)	6 inches seen.

If we may judge from the shape of the ground and from other considerations to be dealt with later (p. 301), this clay is probably a lake-deposit.

(*c*) Mad Brook and Lower Worfe Valleys.—Passing reference has already been made to gravel and shingle composed of erratic material and singularly devoid of Bunter pebbles, which can be traced down these two valleys. The gravels form, with the overlying clay and sands, terrace-like spreads along the flanks of the entrenched valleys. Owing to their superior resistance, compared with the soft Upper Mottled Sandstone, and to the rejuvenation of the streams, the terraces end in abrupt scarps that are cut up by the little tributary valleys. The deposit is usually composed of shingle, of grey slaty fragments, and of gravel containing abundant granites (both Scottish and Lake District), analcite-basalt,[1] porphyries, Wrekin felsites and rhyolites,

[1] *Fide* Mr. T. Robertson, who says that it comes from Ayrshire or Renfrew.

quartzites, coal, ironstone, Llandovery Limestone, and other hard stones the origin of which lies in the north or west. The pebbles are subangular, and occasionally reach 12 inches in diameter. The usual rounded quartzites from the Bunter Pebble-Beds are sparingly represented. Seams of sharp reddish-brown sand, containing fragments of marine shells and abundant pebbles of coal, are associated with the gravel. The deposit varies in thickness up to about 20 feet, and usually is fairly evenly bedded, considering the coarseness of much of the material.

There is not much evidence to prove whether or no these gravels extend under the clays and sands far from the present river; but it seems probable that they do not, and that they occupy the trench-like bottom of a shallow late-Glacial valley, the direction of which nearly coincides with that of the Mad Brook and the Worfe. If this be the case, it is probable that the glacial waters, at times of flood, filled the trench, and in this way gradually amassed enough gravel to obliterate it. It has been suggested above that the sandy clay and sands were deposited more or less contemporaneously from the flood-waters that spread beyond the actual channel, or that covered the gravels in the channel as the amount of water diminished.

The way in which the surface of the deposits drops consistently and evenly from 270 feet O.D. at Brockton to 215 feet at the mouth of the Worfe is well brought out by the section (Pl. XXIII, fig. 2). This section also illustrates the effect of rejuvenation in the overdeepening of the present valley up to Harrington Hall. The Mad-Brook–Lower Worfe Valley was (at the time of the formation of the gravels) an important drainage-line, the thalweg of which was sufficiently graded for the gravels to be deposited.

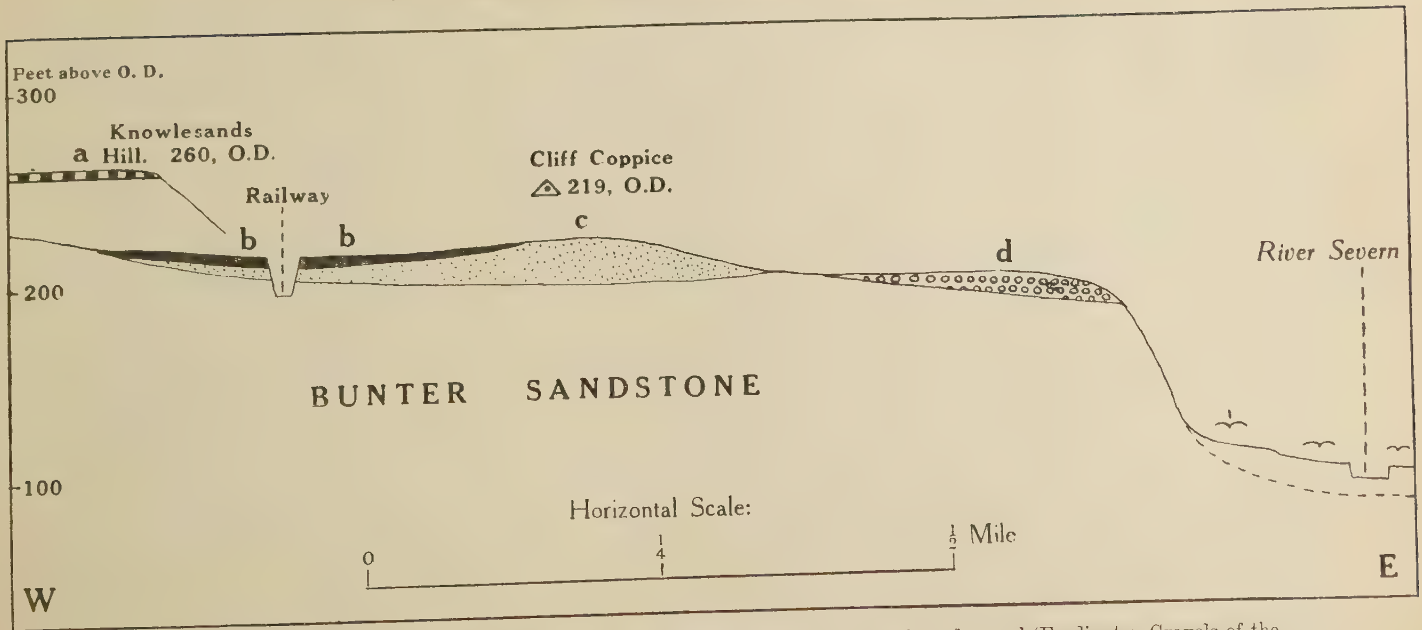
(*d*) Fluvioglacial terrace-gravels of the Severn Valley.

- (1) Gravels at very high levels.
  - (α) Knowlesands Gravel.
  - (β) Hoards Park Gravel } Hoards Park–
  - (γ) Eardington Gravel } Eardington Terrace.
- (2) Main Terrace.

(1) The fluvioglacial gravels, found at very high levels relative to the present valley-floor in the Bridgnorth reach, are of peculiar composition, which renders their interpretation a matter of difficulty.

(α) The Knowlesands Gravel (fig. 6, p. 292).—A thin, practically unbedded gravel caps the hill (260 feet O.D.) at Knowlesands. It consists almost exclusively of irregular nodular pieces of *Spirorbis* Limestone, and possibly of 'Old Red' cornstones. Occasional blocks of sandstone and a very few Welsh erratics (for instance, volcanic ashes from the Berwyn Hills) can be found. No northern erratics have been discovered in this gravel, although large and small northern boulders occur in the neighbourhood up to greater heights.

Fig. 6.—*Sections through Knowlesands Hill and Cliff Coppice.*



a = Limestone-gravel of Knowlesands; *b* = Clay, with northern erratics; *c* = Sands and gravel (Eardington Gravels of the Hoards-Park Terrace), with local and Welsh erratics; *d* = Main Terrace.

It appears possible that this deposit may have been formed under the influence of the Welsh ice-sheet, before the advent of the north-western ice in this district; and that, although overwhelmed by it, the gravel locally escaped destruction. The composition of the deposit recalls that of the morainic gravel at Rhodes Farm (see p. 287).

Similar limestone-gravels have been found at a few other places. Of these occurrences, some are dealt with under the headings β and γ; but one at a point 100 yards east of Quatford Church may, on account of its height, be grouped with the Knowlesands deposit. Here, a thickness of some 4 feet of limestone-gravel is seen at about 235 to 240 feet above O.D. It is overlain by sand, with Bunter pebbles, which reaches to 252 feet. There are several small patches of sandy Bunter gravel near Quatford and Dudmaston, at corresponding heights; but there are no openings in them, and I have seen no sign of the limestone-gravel. Northern erratics occur on their outcrops.

(β) The Hoards-Park Gravel.—This deposit takes its name from a farm about a mile north of Bridgnorth, south of which it was well exposed in 1923. Its upper surface is terrace-like, and lies at about 250 feet O.D., while its base may be as low as 225 feet, or possibly less in places. The present Severn thalweg is here about 100 feet O.D. The following section was made out:—

Sand-and-gravel-pit, a quarter of a mile south of Hoards Park, Bridgnorth.

	Thickness in feet.
(*e*) Fine gravel of limestone-fragments, in places decalcified; containing *Helix* sp. and bones of toads or frogs	$2\frac{1}{2}$ to 3
Obscured by fall, (?) sand .... about	3
(*d*) Loamy brown sand, with coaly streaks .... (*c*) Brown sand, with a thin seam of loamy laminated fine silt in the middle, and a seam of clay at the base	$1\frac{3}{4}$
(*b*) Horizontally-bedded fine gravel, with pebbles, as a rule less than 2 inches in diameter, and thin seams of sand	$2\frac{1}{2}$
(*a*) Very sharp and clean, reddish-brown, quartzose sand, with thin seams of fine gravel	3 +

The gravels, other than the limestone variety, contain few distinctive pebbles; but those collected included one small piece of granite, some greenish volcanic rocks, and a fragment of Ercal Granite from the Wrekin. Much of the material is markedly wind-etched. The limestone-gravel is in places decalcified, and in this material I have found some fragments of *Helix* shells, as also two masses of small bones which Mr. M. A. C. Hinton kindly identified as those of toads or frogs. The shells and bones may both be of recent origin.

Fairly large pebbles of granite are numerous in the adjoining field, but probably do not originate in the gravels just described.

It is probable that Bridgnorth High Town is built in part on sands and gravels belonging to the Hoards-Park deposit; for,

although I have been unable to find any exposure, my friend Mr. J. A. Benjamin dug down 5 feet near the cricket-ground, and obtained reddish sand, with fragments of coal and subangular pebbles of Welsh rock-types.

(γ) The Eardington Sands and Gravels (fig. 6, p. 292).—A somewhat undulating but terrace-shaped area of sands, gravels, and clay stretches from Knowlesands to Eardington and beyond, reaching a height of 219 feet O.D. at the top of the 100-foot cliff that overhangs the Severn. These deposits are separated by a vertical height of 40 feet, and by an outcrop of Bunter sandstone, from the limestone-gravel of Knowlesands. The following sequence can be demonstrated in the cliff and in the railway-cutting:—

Cliff Coppice, Knowlesands.

	Thickness in feet.
(*c*) Reddish sandy boulder-clay, with small northern erratics (granites, analcite-basalt). This lies in a hollow eroded in (*b*). It is probably not a ground-moraine, but a deposit formed in a temporary lake	? 3 to 6
(*b*) Coarse, brownish, sharp sand, with a few stones and fairly numerous fragments of coal	10 to 15 or 20
(*a*) Angular coarse gravel, with nodules of *Spirorbis* Limestone, sandstones of 'Old Red' type, cleaved Silurian slaty rocks (Denbighshire Flag type), chert, dolerite, Uriconian felsites, and fossiliferous limestone. No northern erratics. Base at 190 feet O.D....	about 5

A careful search here was rewarded by the discovery of plentiful Welsh erratics, but nothing that can be referred to a northern origin. In the overlying clay, however, northern erratics are common.

Near Eardington Village, in a railway-cutting by the level crossing, although the gravel is predominantly composed of Welsh and local material, occasional northern erratics were found. South of the village, at 211 feet O.D., there is a coarse gravel-soil in which northern erratics are common.

There are, thus, near Eardington drifts that seem to be respectively Welsh, northern, and mixed. 'In the field' it is not possible to separate, by mapping, the mixed drift near the village from the gravels and sands, (*a*) & (*b*), of the cliff-section. The question, therefore, arises whether (*a*) & (*b*) are really of Welsh origin, and antedate the northern boulder-clay by a considerable period of time; or, whether by some accident, northern boulders have not been incorporated or detected in them. I favour the latter view, although the presence of northern elements in the mixed gravels can be explained on the supposition that they were introduced at the surface from the northern boulder-clay (since eroded away); or that, when in undisturbed gravel, as in the railway-cutting, the northern ingredients are due to the overlap of the Main Terrace

(p. 297) on to the Welsh gravels. The two terraces certainly are very nearly at the same level here.

I am inclined to regard the Hoards-Park and Eardington Gravels as part of the same deposit, which we may call the Hoards-Park–Eardington Terrace. They are related in that they are largely composed of local and Welsh material, and in having apparently been overwhelmed by the northern ice-sheet. At the same time, the presence of occasional northern boulders in the gravels suggests that they were laid down during the advance of the north-western ice, but before the supply of northern erratics was abundant. Their composition stands, for this reason, in strong contrast to that of the Main Terrace, which was built up from material derived from the moraines of the northern sheet. The Hoards-Park–Eardington Gravels may nevertheless have drawn their supply of stones (especially the *Spirorbis* Limestone) largely from the deposits of an earlier (Welsh?) glaciation of which the Knowlesands and Rhodes Farm deposits may be relics.

The Main Terrace.—Sand, shingle, and gravel, almost entirely composed of far-travelled erratics, and containing a surprisingly small number of Bunter pebbles, are found at heights varying from 120 to 85 feet above the present flood-plain. They form well-developed terraces that can be grouped together as the Main Terrace of the Severn. It will be shown in the sequel that the lower terraces are of essentially the same composition.

The nature of the gravels of the Main Terrace may be illustrated by the following sections:—

The Grove Gravel-Pit, east side of Bridgnorth Low Town (Pl. XXII, N).

	Thickness in feet.
Soil	$1\frac{1}{2}$
Gravel	1
Well-bedded fine sand[1]	1 to $1\frac{1}{4}$
Coarse gravel	$4\frac{1}{2}$
Fine sand, with coal-pebbles[1]	$1\frac{1}{4}$
Fine shingle	$1\frac{3}{4}$
Well-stratified coarse gravel, with seams of sand ...	4
Lower Mottled Sandstone	———

Both gravels and sand are fairly horizontally-bedded. The larger stones are subangular, and range up to a foot or more in diameter; while 50 to 60 per cent. of the whole deposit is made up of a fine shingle of flat, more or less waterworn, grey slate-pebbles, doubtless of Welsh derivation. Maw (*op. cit.* p. 141) records one specimen of *Purpura lapillus* from these gravels; but I have only seen minute chips of shells. The following erratics were noted at the Grove Pit:—Scottish granites (grey), Eskdale granite, ? granophyre, mica-schist, analcite-basalt, grits and conglomerates

[1] No longer exposed (1923), the whole being gravel and shingle.

(? pre-Cambrian), Uriconian felsite, Caradocian sandstone with *Trinucleus* and *Orthis* (possibly from Montgomeryshire),[1] slaty rocks of the Silurian types met with in the Berwyn Hills (common), Llandovery Limestone (common), Wenlock Limestone (rare), Carboniferous Limestone and chert, coal, and ironstone. Bunter pebbles are rare.

Between Bridgnorth and Danesford, 250 yards north-east of Danesbridge Lodge, there is an overgrown pit in which the material is very coarse, and almost devoid of bedding. The following boulders were noted:—Carboniferous and Llandovery Limestone, Wrekin rhyolite, granites, slates, analcite-basalt. This is the locality *x* in Pl. XXIII, fig. 1, mentioned below, where the gravels descend 20 feet below the normal thalweg-curve.

At the mouth of the Worfe Valley, and south-east of Apley Gates, a sandy clayey wash overlies coarse gravel with a slight dip towards the hillside. Wrekin rhyolite, porphyries, granites, grits, flint or chert, and coal were noted, but Bunter pebbles are very rare or absent, although the gravel lies at the foot of the Pebble-Bed escarpment.

The following section was seen in the gravel-pit in Apley Park, north-west of the house:—

	Thickness in feet.
Reddish-brown sand	3
Medium gravel, stones up to 8 inches in longest diameter...	8
Coarse boulder-gravel, many stones being from the Carboniferous rocks of the district	5

North of Apley, in the narrow gorge which the Severn has cut in the Coal Measures, only two patches of these gravels are known. One near Swinney is more of a mound than a terrace in its present shape: it rises almost to 300 feet O.D. from its base at about 260 feet. The second (just described), a quarter of a mile north-west of the mansion of Apley Park, is more terrace-shaped, with its upper surface at about 250 feet O.D. and its base at about 220 feet.

But, from Apley southwards to Dudmaston, on the Lower Bunter Sandstone outcrop, the Main Terrace provides a conspicuous feature of the landscape wherever it is preserved. The gravels form flat spreads, bounded on their riverward sides by steep scarps. The heights of the bases and tops of the gravel-spreads, determined from levels on the 6-inch Ordnance maps and by aneroid measurements, have been plotted on the diagram-section Pl. XXIII, fig. 1. The following features will be noted:—The curve B W B′ passes through the lowest points at which any of these gravels have been observed, with the exception of the two spots *x* and *y*. I am not satisfied with the accuracy of the observation at *y*; but at *x*, north-west of Danesford, the gravels certainly descend 20 feet below the curve. This is possibly explicable as an occurrence of gravel filling in a deep hole in the old river-bed. The curve B W B′

[1] Derivation kindly suggested by Mr. W. B. R. King, F.G.S.

may be termed the 'thalweg-curve' of the Severn at the time when the Main Terrace was formed.

In the same figure the thalweg-curve of the gravels of the Worfe Vale (W W′) is seen to form the natural continuation of the curve B W; the part W B′ belongs to the Severn, and is at a distinctly steeper gradient than W W′. These features accord well with the maturity of the Worfe Vale and the more youthful character of the Severn Gorge, in which the gravels are respectively located.

The curve C C′ passes through the summit-levels of most of the well-marked terraces, and may therefore be regarded as marking the approximate level to which aggradation took place when the gravels were deposited. But there are indications that locally they accumulated to slightly greater heights.

The line W″ W‴ is a similar curve, showing the aggradation of the fluvioglacial gravels in the Worfe Vale. Though the sub-gravel thalwegs in the two valleys are graded to one another, it will be noted that aggradation seems to have gone on to a greater extent in the Severn Valley (C C′) than in the Worfe (W″ W‴). Nevertheless, it is clear that the gravels of the Worfe and the Main Terrace of the Severn represent two parts of a single deposit, laid down after erosion had produced a graded condition in both valleys, the nature and history of the two being sufficiently unlike to account for any difference of gradient or of aggradation observed (see p. 305).

The relation of the Main Terrace to the Hoards-Park–Eardington Terrace is well shown in the sections (Pl. XXIII, fig. 1, & fig. 6, p. 292). Near Eardington the upper surface of the Main Terrace lies above the level of the base of the older gravels; but the two are separated by an outcrop of 'solid rock' at Cliff Coppice (fig. 6) and at Hoards Park.

River-terraces and alluvium (post-Glacial).—Of the same lithological composition, but less conspicuously developed than the Main Terrace, is the Upper Danesford Terrace, the upper surface of which lies about 15 to 20 feet below the rock-platform on which the Main Terrace rests, and about 65 to 70 feet above the present alluvium.

A third, or Lower Danesford Terrace, may be traced in Apley Park and south of Bridgnorth, about 30 feet above the present alluvium. Corresponding with this is a well-marked terrace from Cressage to Sheinton, at a slightly lower level relative to the river. The latter occurrence may indicate that, at the date of formation, aggradation was going on in the Shropshire Plain, as well as in the wider parts of the gorge.

The alluvium in the Shropshire Plain is wide, in parts of the gorge it is absent, and even in the more open valley by Bridgnorth it is barely a quarter of a mile across. It lies at a height of about 10 feet above the low summer-level of the river, though it rises in places to heights that can but rarely, if ever, be covered by floods.

Opposite the mouths of the small tributaries this is conspicuous. Each has, in fact, a diminutive alluvial cone, despite the absence, with few exceptions, of any surface-stream in them at the present day. These higher parts of the alluvium in places are made of sand, which probably descends to below the present flood-deposits. If this be the case, aggradation to at least the level of these upper alluvia preceded the conditions that now prevail, under which practically nothing but silt and mud is accumulating.

V. An Attempt to Explain the Foregoing Data.

(*a*) Pre-Glacial Topography.[1]

It seems possible to deduce from the data brought forward, that in pre-Glacial times the plateau across which the Severn Gorge now runs, sloped almost uninterruptedly towards the Mad Brook-Worfe Valley, along which lay the principal line of drainage both for ice and for water as far south as the latitude of Worfield. Hereabouts the drainage turned at first westwards, and then southwards along the present Severn Valley.

Across the site of the present gorge at Iron-Bridge, the plateau stretched at a height of about 500 feet O.D., probably sagging to a col near Iron-Bridge at about 470 feet. This contention is based on the occurrence of lake-silts at about 460 feet at Lincoln Hill (Pl. XXII, LH) and of boulder-clay at 500 feet O.D. near Madeley Wood Colliery (Pl. XXIII, M). Both occurrences lie on the crest of the steep valley-sides of the gorge (see sections, fig. 2, p. 280).

On the western side of the plateau near Iron-Bridge, Coalbrookdale and other smaller obsequent brooks united near Strethill and Buildwas to form a tributary flowing westwards to the ancient Severn in the neighbourhood of Shrewsbury. The valleys of these streams had been already excavated as deeply as the present Coalbrookdale and the Severn Valley in the Buildwas Strath.

On the site of the Severn Gorge there was probably a small tributary of the Worfe, rising on the south-eastern side of the Iron-Bridge barrier. It barely notched the surface of the plateau: near Apley Park it joined the waters of the Dean and Linley Brooks. The valley-bottom here was then at about 300 feet O.D., or some 180 feet higher than at present.

The Coalport Brook, which now takes the water from the eastern end of the Lightmoor Gap and from Madeley, did not then exist. The drainage of that area lay down the Mad Brook. This is indicated by the distribution of the drifts round Cuckoo Oak; by the character of the valley of the Coalport Brook, mature above and very youthful below Madeley; and by the very low watershed that now separates this stream from the Mad Brook (see p. 283 & Pl. XXIII, fig. 2).

[1] The term pre-Glacial is used here to refer to the conditions that preceded the last Glacial episode in this district.

The Worfe and its tributaries now flow at the bottom of a trench-like inner valley cut in an open wide vale. The inner valley has been excavated through the Glacial and Fluvioglacial deposits, and through a varying depth (0 to 100 feet) of Bunter sandstone. We can see from the distribution of the drift that, but for this inner overdeepened trench, the general level of the ground was not greatly different before its advent, and that the configuration was that of a mature drainage-system.

(*b*) The Advance of the Ice-Sheet.

In tracing out the history of the Glacial events in this area we are, I contend, justified by the evidence in assuming the non-existence of the Iron-Bridge Gorge. If this be granted, it follows, as suggested by Lapworth and by Harmer, that the Irish Sea ice-sheet advancing from the north-west must have impounded the rivers draining into the Shropshire Plain in a series of lakes, one of which occupied the Buildwas Strath and Coalbrookdale; while others came into existence near Wellington and Oakengates, and Newport (Salop).

It is doubtful how far we have in the drifts any record of these early lakes and their overflows. It may be that the spread of sand and gravel at the Lightmoor col, and down the Madeley Court valley to Cuckoo Oak and the Mad Brook, was produced by the overflow of the Buildwas Lake. The formation of these deposits during the advance of the ice is suggested by the fact that they are overlain by the boulder-clay.

The Hoards-Park–Eardington Terrace may have been formed during the advance of the north-western ice. Reasons for this view have already been given on p. 295.

The ice advanced into the district probably in part from the west, as attested by the abundance of Llandovery Limestone-boulders as far north as Brockton in the Mad Brook valley, but in part from the north-west or north. In whatever direction it came it had to cross the old watersheds athwart its course. In many localities, only large erratics remain to testify to its former presence. This feature is doubtless the result, primarily, of widespread subsequent denudation, but may be in part due to the cleanness of the upper ice that alone surmounted the old watersheds. Although it is not known for certain how far south the ice-sheet extended, the southerly limits laid down by Mackintosh [1] appear to be correct. The ice probably covered all the district under description, except the parts of Shirlett Common that exceed 700 feet in height, and the high ridge south of Morville.

Northern drift on the top of the high escarpment of the Ludlow rocks near Bourton, south-west of Wenlock, is recorded by Maw [2]

[1] D. Mackintosh, Q. J. G. S. vol. xxxv (1879) p. 437.

[2] G. Maw, *ibid.* vol. xx (1864) pp. 132, 139 & D. Mackintosh, *op. supra cit.* p. 442.

at 700 to 800 feet O.D., and I have seen several granite-boulders here at 900 feet O.D.

The big concentration of boulders at Mose, a mile and a half south-east of Quatford, may be terminal in origin.

(c) The Principle of the Ice-Withdrawal.

Evidence in the field supports the view which is suggested by *a priori* reasoning, that the ice occupying the North Shropshire Plain maintained two lobes in this area for a long time after the ice-withdrawal began. One lay in the Wenlock-Sheinton-Buildwas Valleys; the other, east of the pre-Glacial watershed, occupied the drainage-basin of the Worfe (that is. the Worfe and the present Severn). As the ice retreated, the V-shaped neck of bare land separating these lobes increased; but the two lobes were confluent throughout in the north, at the apex of the V. The ice-thrust from the north-west kept the Wenlock-Sheinton-Buildwas lobe pressed, counter-drainage, against the old watershed as it was uncovered. Marginal lakes were formed here.

East of the watershed, the ice was fed from the north or from the north-west over high ground, and the retreat was consequently at first more rapid.[1] The melt-waters tended to travel marginally between the ice and the bared land, and to find their way into pre-existing valleys draining southwards. The overflow-waters of the lakes west of the divide were added to the marginal rivers.

(d) Stages in the Retreat.

Stages in the retreat of the ice can be traced only in a very rough way; partly by actual marginal deposits, but mostly from physiographical considerations based on the distribution of the drifts in relation to the topography. However, for the sake of clearness in description, I propose to adopt tentatively a number of such stages. and I have ventured to indicate them on the map (Pl. XXII,[2] & fig. 7, p. 302); but it must be realized that these positions are in many instances unmarked by moraines, kames, or other marginal deposits upon which one usually relies.

In perusing the following description, reference should be made to fig. 7 (p. 302), in which the various ice-stands, lakes, and glacial rivers are sketched in outline.

Stage I.

Ice-front. West of the watershed[3]; unknown, but may have lain along the watershed.

East of the watershed: Barrow, Upper Linley Brook, east of Morville, Lower Mor Brook.

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[1] Ice persisted for a very long time in the low ground of the Worfe Vale, owing to the lowness of the old watershed south-east of Newport.

[2] I have been assisted in this by valuable criticisms and suggestions made by my friend, Mr. E. E. L. Dixon, F.G.S.

[3] See p. 276.

Four sub-stages can be distinguished here, and are indicated on the map (Pl. XXII). I *a*—This is based on the occurrence of a valley west of Rhodes Farm, the cutting of which is best explained as a marginal phenomenon, before the deeper valley at the Smithies (1 mile south-west of Linley) had originated.

I *b* involves a re-advance of the ice. At this stage the marginal waters from Barrow southwards, passing through the Smithies Col, entered a lake in the Upper Mor Brook Valley (fig. 7, p. 302, M). The ice itself impounded this by impinging on the high escarpment on the south of the valley. The sand-and-gravel-mounds east of Morville, and the higher terrace-like spreads near the village were laid down at this stage (p. 289). Maximum height of water=about 370 feet O.D.

Retreat to I *c*, by opening lower exits for the water of the lake, gave rise to the lower terraces round Morville, and eventually to the Bridgwalton sands and gravels (p. 289). The lake now stood at about 300 feet O.D. (fig. 7, p. 302, M1).

In Stage I *d*, the small ridge of gravel at Houghton, and the clays of Morville Heath, p. 290, appear to have been formed, the latter in the lake-like depression, north-east of the Bridgwalton sands (fig. 7, p. 302, H). The ice-stand I*d* is necessitated by the existence of the small valley from Houghton, past Croft, which then took the drainage that at I *a* went down the eastern branch of the Tiddle Brook.

The curious distribution of the drainage-lines, and their relation to the drifts have been taken into account in localizing the different ice-fronts.

Stage II.

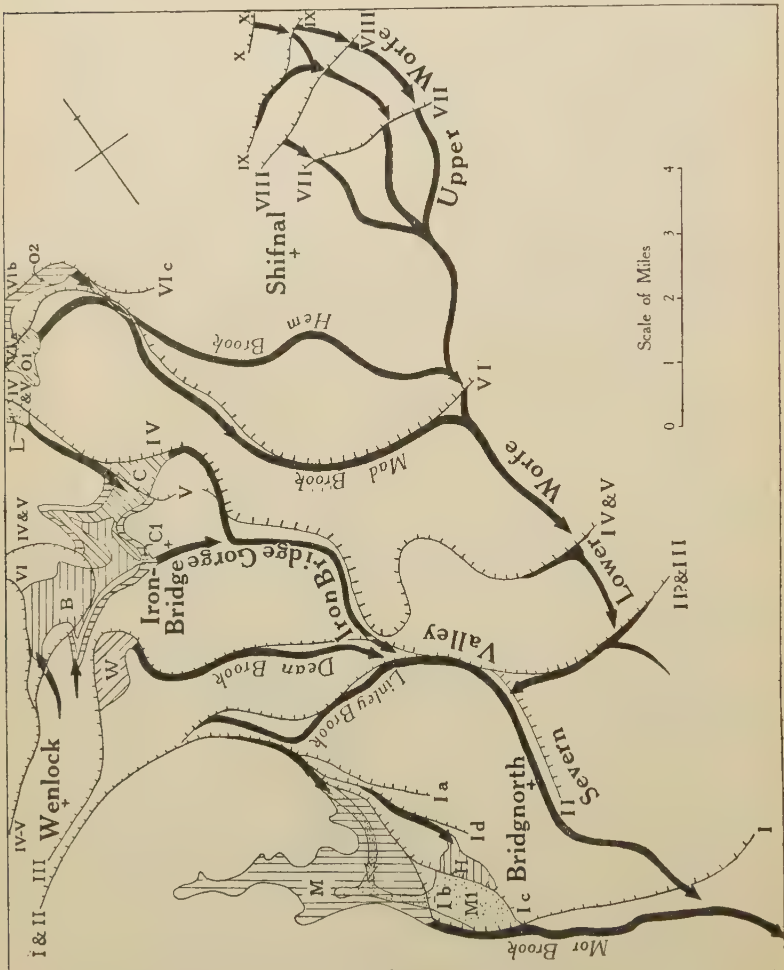
Ice-front. West of the watershed; probably as in the 1st Stage.
East of the watershed; Barrow, line of the Linley Brook, line of the Severn Valley to the mouth of the Worfe, from here probably along the line of the Severn at first, and later perhaps along the west-to-east part of the Worfe.

The retreat to this position appears to have opened up a pre-Glacial valley—the Lower Linley Brook—and thus diverted the marginal flow from the Smithies-Morville valley into the present Severn Valley at Apley. The morainic gravels in the Linley Brook valley (p. 289) are regarded as dating from this time.

The Severn Valley, south of the mouth of the Worfe, now functioned as an important drainage-line, receiving the marginal waters of the eastern ice-lobe through the Linley Brook, and perhaps at a later sub-stage through the lowest part of the Worfe.

Erosion predominated over deposition in the Bridgnorth reach of the Severn at this time; but, downstream, the building-up of the Main Terrace may have been proceeding, the valley in its lower reaches having already been excavated to base-level by the melt-waters during the advance and maximum development of the ice-sheet.

Fig. 7.—*Skeleton-map of the Iron-Bridge Gorge and the Worfe Vale, showing the ice-stands I to X; the Glacial rivers; and the Glacial lakes at: M and M1, Morville; H, Morville Heath; W, the Wyke; C, Coalbrookdale at the Lightmoor outlet; C1, Coalbrookdale at the Iron-Bridge outlet; B, Buildwas; L, Lawley; O1, Oakengates at the Mossey Green outlet; O2, Oakengates at the Oakengates Col outlet.*



Stage III.

Ice-front. West of the watershed; east of Wenlock, southern end of Benthall Edge, Posenhall Col; impounding a lake [fig. 7, W] (or lakes) that may have overflowed by the Posenhall Col.[1]

East of the watershed; Posenhall Col, line of Dean Brook, Apley, line of the Severn to the mouth of the Worfe, line of the Worfe to Worfield.

This line is better marked than Stage II by terminal deposits: namely, the gravel-kames on both sides of the Posenhall Col, p. 287; the Dean Corner morainic gravels, pp. 287, 288. The more terrace-like gravels near the mouths of the Linley and the Dean Brooks may also belong here (p. 289).

The Dean Brook and Severn below its mouth now formed the principal line of drainage, with perhaps the Lower Worfe as a small feeder. Erosion still predominated in the Severn Valley, and in the Worfe Vale as far as it was unbared. It is probable, however, that most of the latter was still ice-covered, for the northerly ice-thrust over the low watershed near Newport, hindered the recession by maintaining the supply of ice in the open vale.

Stage IV.

The western and eastern ice-lobes retreated so far as to leave bare all the plateau west of the Severn, and much of the high ground north of Iron-Bridge. They were still united on the north side of the Wrekin Massif.

Ice-front. West of the watershed; ? line of Wenlock Edge, ? west side of Tick Wood and Benthall Edge, west side of the Wrekin Massif.

East of the watershed; the Coalmoor Col, line of the Horsehay Brook, Lightmoor, line of the Coalport Brook, line of the Severn from Coalport to Apley, Norton, the Echoes Hill Kame (p. 286), Merecot (p. 286), and so eastwards.

West of the watershed the ice impounded a lake or lakes, one of which covered Coalbrookdale (fig. 7, C). Its waters first drained out at about 450 feet O.D. along the ice-front at Lightmoor, and lowered the outlet to about 370 feet by cutting the Lightmoor overflow-valley (p. 283). Some of the Strethill-Buildwas Sands (p. 277) and of the Lincoln-Hill Silts (p. 281), and possibly some of the stoney clay at high levels in Coalbrookdale (p. 284) may have been formed in this lake, which we may term Glacial Lake Coalbrookdale. The waters from the western edge of the eastern lobe, together with a possible overflow from a lakelet in the Lawley Valley (fig. 7, L), descended the Horsehay Valley, and emptied themselves into the lake. Some of the curious abandoned channels south of Horsehay may have been cut at this time along the ice-margin (p. 283 & fig. 3, p. 281).

The overflow at Lightmoor from the Coalbrookdale Lake,

[1] Note the lacustrine clays near Wenlock and Wyke (Pl. XXII, W).

together with the marginal drainage of the ice-sheet, appears at this time to have been carried away by the embryonic Coalport Brook into the present Severn Valley. Thus the reach from Coalport to Apley may be regarded as having originated as a marginal channel, although it is possible that this follows a slight pre-Glacial valley.

If the ice-front was as here suggested, conditions in the Worfe Valley were similar to those outlined in Stage III. The Echoes-Hill Gravels are regarded as a glacieluvial kame (p. 286).

Stage V.

The ice-front was in the same general position as in Stage IV, but a slight re-advance had closed the Lightmoor overflow-valley.

It is necessary to postulate the re-advance and the blocking of the Lightmoor overflow-channel, since only in this way can we account for the diversion of the waters of the Coalbrookdale Lake from Lightmoor to the present Iron-Bridge Gorge. Ice must have occupied the col up to about the 500-foot contour.

The result of this was the raising of the level of Lake Coalbrookdale (fig. 7, p. 302, C1). The Lincoln-Hill Silts (p. 281) were mostly deposited now. Low mounds of clayey gravel (p. 284) inside the Lightmoor overflow-channel are regarded as evidence for this re-advance.

It is possible that the re-advance is further demonstrated in the valley of the Upper Horsehay Brook, by the abandonment of parts of the old course, and by the establishment of the present one as a new marginal channel (fig. 3, p. 281).

Debarred by ice from the Lightmoor Col, the waters of the lake escaped over the watershed at about 470 feet O.D., at a point where now is the Iron-Bridge Gorge, into what was then a slight valley, tributary to the Coalport Brook. The level of the valleys where they joined at Coalport must have been a little below 300 feet O.D.; for the present 'hanging' upper part of the Coalport Brook valley is at some 320 feet O.D. at Cuckoo Oak. Consequently, the waters issuing from Lake Coalbrookdale over the Iron-Bridge watershed at 470 feet O.D., had a rapid fall of 170, or perhaps 200, feet in about a mile. A débâcle occurred.

We must assume the rapid excavation of a gorge. The lowering of the outlet at Iron-Bridge soon reached a level below 365 feet O.D., for otherwise the Lightmoor Col (which was at about this level) would have acted a second time as the overflow-channel of Lake Coalbrookdale so soon as the ice-front had again receded. The further lowering of the outlet below 365 feet O.D. was effected more or less concurrently with the events to be described under Stage VI. I propose, therefore, to defer the description of the subsequent development of the gorge at Iron-Bridge, and of the lake in Coalbrookdale until later (pp. 306–308).

Stage VI.

The ice-front round the west and north-west sides of the Wrekin Massif was much as in the 5th Stage, but slight withdrawal had enlarged the impounded lakes in Coalbrookdale and the Lawley Valley (fig. 7, p. 302, O1), and later created a third lake (fig. 7, O2), eventually confluent with Lake Lawley, at Oakengates. The two sub-stages are suggested on the map (Pl. XXII, VI *a* & VI *b*).

East of the watershed, the ice-front may have run thus:—Oakengates, Malins Lee Station, southwards along the high ground between the Mad and the Hem Brooks, line of the Mad Brook, and so eastwards.

In this stage the lake in Coalbrookdale was enlarged to cover the Buildwas area, and may be called Glacial Lake Buildwas (fig. 7, p. 302, B). Its outflow continued to erode the Iron-Bridge Gorge.

In Sub-Stage VI *a* the lake in the Lawley Valley (fig. 7, O1) drained out at Mossey Green (Pl. XXII, MG) into the Oldpark Brook, at that time the head of the Mad Brook; but in Sub-Stage VI *b* it became confluent with Glacial Lake Oakengates (fig. 7, O2), which flowed out over the Oakengates Col—also into the Mad Brook. South of the col the overflow ran along the ice-margin for some distance. Thus was cut the flat-bottomed through-valley from the present watershed southwards to beyond Malins Lee Station, which is followed by the Madeley Branch of the London, Midland, & Scottish Railway.

The present meagre drainage from the Oakengates watershed loses its way near Malins Lee Station among the low mounds forming the floor of the valley, from which it escapes by a drain to form part of the Hem Brook. But, at this stage, a great river flowed southwards into the Mad Brook, the Hem Brook Valley being still under a mass of ice which at this point constituted the eastern flank of the overflow-channel.

The Mad Brook and the Lower Worfe thus received the marginal drainage of the eastern ice-lobe, together with the overflow waters from Lake Oakengates. At first, renewed erosion took place, so that the thalweg of the Worfe and of the Severn (below the Worfe) became finally graded (Curve BWW′ in Pl. XXIII, fig. 1). Later the Main Terrace near Bridgnorth (p. 295) and the fluvioglacial deposits of the Mad Brook and the Worfe (p. 290) were laid down.

The latter slope gradually southwards at about the same gradient as the thalweg upon which they rest. The gravels follow the present incised Worfe Valley like a river-terrace; but, when we consider the sub-drift surface-configuration, it seems that they occupy a former river-channel, in places a quarter of a mile wide, and some 20 to 25 feet below the general level of a flat plain. On each side of the gravels stretch clays and sands (p. 285), which are probably deposits laid down by seasonal floods outside the normal channel. The river may have been unusually liable to such floods,

on account of its waters being dammed back at its mouth by the accumulation of gravels in the Severn Valley; for these gravels, which now form the Main Terrace, were built up to a level which, opposite the mouth of the Worfe, is distinctly higher than that attained by the corresponding fluvioglacial gravels of the latter (compare CC′ with W″ W‴ in Pl. XXIII, fig. 1).

The drainage-system outlined above may have persisted for a long time. The quantity of gravel down the Mad Brook, the Worfe, and the Severn; the size of the Oakengates overflow-valley; and the absence of any other col that could take the overflow of the Oakengates Lake until the ice had bared the watershed at the head of the Worfe Valley (see p. 310), all point to this. It is probable, however, that, in the later stages of the Oakengates overflow, the Hem Valley and later the Wesley Brook became free of ice, and took part at least of the water (Pl. XXII, C & fig. 7). We may correlate the gravels at Evelith and Shifnal (p. 286) with this condition, noting that they are covered by a wash of clay, in the same way as those of the Mad Brook and the Lower Worfe.

It must be borne in mind that these events in the Worfe Basin were progressing concurrently with the excavation of the Iron-Bridge Gorge by the outflow from Lake Buildwas. This proceeded until a gradient was attained, steeper than in the Worfe Valley (compare curve BWB′ with BWW′, Pl. XXIII, fig. 1), but sufficiently low to allow gravels to be formed at Swinney,[1] in the narrow gorge, and from Apley downwards in the wider part. If we continue this thalweg-gradient-curve by extrapolation to Iron-Bridge, it attains a height of about 300 feet O.D. This is an important point, for it gives a clue to the level of the outlet of the lake that occupied the Buildwas Valley and later, perhaps, the Shropshire Plain. The establishment of a graded condition in the river-valley below Iron-Bridge may account for the outlet, and with it the lake, having remained at approximately the same height for a long period.

Glacial Lake Buildwas.

It has been shown above that the Iron-Bridge overflow originated from a small ice-dammed lake that occupied Coalbrookdale (fig. 7, p. 302, C1). Its level at first was about 470 feet O.D. The lowering of the outlet at Iron-Bridge governed the surface-level, while the withdrawal of the ice westwards increased the area of the lake and the volume of its overflow. The enlarged lake may be termed Glacial Lake Buildwas (fig. 7, B). In it were laid down partly as marginal, and partly as deltaic deposits, the Buildwas and Strethill Sands with their accompanying gravels, clays, and silts (p. 277). The sands may have been thrown down in the lake by the river which drained the Wenlock Valley when the ice stood along Wenlock Edge. Two deep valleys may

[1] These gravels may, however, be marginal deposits formed during Stage IV or Stage V, pp. 303, 304.

mark the positions of this river at slightly different stages in the ice-withdrawal: namely, Hunger Dale descending from Tickwood Hall, and the Farley Dingle followed by the Wenlock–Buildwas road and railway (see fig. 7, p. 302). The large blocks of boulder-clay included in the sands at Buildwas Abbey (p. 279) may have been dropped from icebergs. It would be interesting to know whether the boulder-clay recorded by G. Maw at Strethill,[1] had a similar origin. Does the presence of boulder-clay towards the middle of the Buildwas Sands, in the two cases, indicate a re-advance of the ice, such as we have noted between Stages IV and V?

The present shape of the Buildwas and Strethill sand-mounds is, as originally pointed out by Maw (*loc. cit.*), the result of subsequent denudation; but their highest points rise to about 300 feet O.D., a height which coincides with the outlet-level at Iron-Bridge that can be deduced from the gradient of the Main Terrace.

Glacial Lake Lapworth.

Mr. E. E. L. Dixon has found much evidence in the shape of old strand-lines in the Shropshire Plain near Newport (Salop) of an extensive lake, the waters of which reached to about 300 feet O.D.[2] He informs me that he found evidence of it from Newport to the Severn.[2] It is probable that this lake stretched across Shropshire and into Cheshire. Mr. Dixon (*in litt.*) suggests to me that this lake, following the precedent of 'Glacial Lake Agassiz', should be called Glacial Lake Lapworth, since it was Charles Lapworth's genius that first conceived its existence. Lake Lapworth came into being when the lake around Newport was united with Lake Buildwas by the withdrawal of the ice-front from the foot of the Wrekin massif.

The lake appears to have had two outlets: one (309 feet O.D.) at Gnosall into the Church Eaton Brook,[2] and so into the Trent; the other the Iron-Bridge Gorge, which eventually took the whole outflow.

As the ice-sheet withdrew northwards, an ever-increasing catchment-basin was liberated to drain into the lake. The increasing volume of the outflow (probably in combination with renewed uplift of the land relative to the sea) eventually led to the deepening of the outlet at Iron-Bridge after the stage of apparent equilibrium at 300 feet O.D. that is indicated by the old shore-lines, by the height of the Buildwas Sands, and by the deposition of the Main Terrace of the Severn. Lake Lapworth would have come to an end when a lower exit for its waters had been laid bare by the retreat of the ice to the neighbourhood of the present coast-line. But, before this occurred, erosion of the

[1] Q. J. G. S. vol. xx (1864) p. 133.

[2] E. E. L. Dixon, 'Summary of Progress of the Geological Survey for 1920' Mem. Geol. Surv. 1921, p. 20; see also R. W. Pocock, do. for 1922, Mem. Geol. Surv. 1923, p. 35.

outlet at Iron-Bridge must have lowered the level of the lake sufficiently to divide it into two, along the present watershed between the basins of the Dee and Mersey and that of the Severn. The waters must, in fact, have been lower than the lowest point on that watershed; for, otherwise, the lake and with it the Upper Severn, would have drained northwards to the Irish Sea, on the opening-up of a lower exit along the coast. There is some doubt as to the height of the watershed at that time,[1] owing to possible alterations in the drainage that may have occurred subsequently; but it was probably about 240 feet O.D. at its lowest point.

Although the evidence lies outside this district, it may be reiterated that uplift of the whole region relative to sea-level appears to have taken place concurrently with the events just outlined. It was this uplift, together with the increasing volume of water entering and escaping from Lake Lapworth, that led to the rejuvenation of the Middle and Lower Severn after the deposition of the Main Terrace. That the rejuvenation was propagated irregularly is suggested by the presence of the lower river-terraces; but an explanation of these phenomena cannot be attempted from the data in the Bridgnorth district.

One of the effects of the rejuvenation was the increased activity of all the tributaries. This is especially well seen in the case of the Coalport or Madeley Brook. This is a typical hanging valley. The part above Madeley Market Railway-Station, once occupied by the Lightmoor overflow, is wide, flat-bottomed, and alluvium-covered; the part below is a steeply falling, V-shaped torrent-valley resulting from the rejuvenation.

VI. The Late-Glacial Gravels of the Upper Worfe and the Tong Brook.

The story of the further development of the Worfe Valley is given in the following pages, in which I have been assisted by Mr. E. E. L. Dixon, B.Sc., F.G.S., of H.M. Geological Survey, who mapped part of the area officially. I am much indebted to him, not only for collaborating herein, but for helpful suggestions and criticisms in connexion with the whole problem.

From Ryton northwards to the neighbourhood of the Watling Street near Sheriff Hales, the Worfe and its tributary, the Tong Brook, follow the outcrop of the Upper Mottled Sandstone. The drifts of this stretch are mostly sands, and occasionally gravels, that form a thin sheet over the soft Bunter. Consequently, it is extremely difficult to distinguish the boundaries of the drift. South of Lizard Hill the only outcrop of boulder-clay that could be mapped was found at Hatton Grange, although smaller patches were noted near Stanton, which were too intimately mixed up with the sands and gravels to be mapped separately. The clay is there so sandy that, when ploughed, it produces a loose sand-soil. It is possible that some of the ground regarded either as sandy drift or

[1] R. W. Pocock, 'Summary of Progress of the Geological Survey for 1922' Mem. Geol. Surv. 1923, p. 35.

as Upper Mottled Sandstone may have had a thin spread of unbedded sandy clay upon it.

It is, however, clear that the sandy and gravelly drift is somewhat later in origin than the boulder-clay. This relationship can be deduced from the way in which the boulder-clay west of Lizard Hill is cut through by the gravels, and also, to some extent, from the sections in Monk's Wood, south of Stanton (Pl. XXII, K). In these old quarries the mingling of gravel and boulder-clay is so intimate that a marked break in time between them seems improbable.

The drifts of the Upper Worfe Basin are essentially composed of Triassic débris—sand and pebbles from the Bunter Pebble-Beds. In places, however, there are scattered on the surface fairly numerous large Scottish granite-boulders, and also a few felsites that may have had a Welsh origin. The gravels contain remarkably few erratics, in contrast with those of the Mad Brook and the Lower Worfe. It is obvious that they were deposited by waters draining an area in which erratic material was more sparsely distributed and of a different composition. South of the junction of the Mad Brook with the Worfe I have not been able to recognize this Bunter Drift as a specifically distinct formation, although there are indications at Ryton and north of Worfield of a terrace in which Bunter material is conspicuous, at a slightly lower level than the main fluvioglacial gravels.[1]

It will be seen from the map (Pl. XXII) and section (Pl. XXIII, fig. 2) that the drifts have a wide outcrop, across which the Worfe and the Tong Brook flow in narrow incised inner valleys. The longitudinal section brings out the steady drop of the sheet as a whole, from north to south; but nearer inspection seems to show that the sheet is composed of a series of fans and valley-trains, the earlier formed and southernmost being in part cut through by later more northerly fans and valley-trains.

I am indebted for this conception and for much information about the upper part of this complex outwash-fan to Mr. Dixon, who mapped the northern part of it. In his opinion, these sands and gravels were deposited from a retreating ice-front aligned roughly east and west. There were pauses in the retreat, during which the ice-front remained stationary or even advanced slightly. In the pauses, outwash-fans accumulated at the mouths of the sub-glacial streams, while, lower down the valley, the issuing waters deposited valley-trains, and tended to remove parts of the previously formed fans and trains. On the map (Pl. XXII) the general spread of gravel and sand has been subdivided into a possible series of outwash-fans and trains, referable to four recessional positions of the ice-front[2] (Pl. XXII, vii–x).

[1] These gravels are shown in Pl. XXIII, fig. 2, although no reference is made to them in the explanation of that figure.

[2] Near Newport, Mr. Dixon has found that outwash-fans are well developed, and give evidence of three later positions of the ice-front. At the southernmost of these the alignment has changed to east-north-east and west-south-west, while northwards the swinging-round has continued to a north-north-easterly and south-south-westerly trend, *op. cit.* p. 20.

If Mr. Dixon's views be correct, as I myself believe them to be, the following features would be accounted for:—

(*a*) The sands and gravels, taken as a whole, form a deposit that slopes fairly uniformly down stream, and in this resemble a fluviatile deposit; but, in detail, parts of the deposits rise to considerable heights above adjoining portions.

(*b*) The intimate relations of boulder-clay, sand and gravel, and solid Bunter, seen in the Monk's Wood sections, might be due to the outwash-material following immediately on the laying-bare of the ground-moraine, with possible complications caused by the re-advance of the ice.

(*c*) The thin sheet of sandy and sometimes clayey material, so difficult to map, west, north-west, and north of Hatton Grange, might represent the outwash material away from the principal water-courses, and so correspond in origin to the sand and clays farther south (see pp. 285 & 286).

(*d*) The large spread of gravel west of Lizard Hill, the elevated ridge of coarse gravel south of the Inn on Crackley Bank, and the conspicuous fan of gravel west of Gorsey Bank, all lie in positions that are alone explicable on the hypothesis of their deposition at the actual ice-front.

There is no evidence of any considerable overflow having occurred across the col at the head of the Worfe Valley, after the ice-front had withdrawn to the north of the watershed. The col is indicated on the map (Pl. XXII) by the letters G B (Gorsey Bank). Its height is about 350 feet O.D. (see E. E. L. Dixon, *op. cit.* p. 19).

Later waters (post-Glacial ?) that descended the valleys of the Worfe and the Tong Brook, not only cut into, but re-sorted the material of the outwash fans. As a record of this, we find a series of tiny patches of gravel fringing the riverward edges of the sheet, and behaving like remnants of a fluviatile terrace. Such patches are shown black in Pl. XXII, and are well developed near Cosford. Being concentrates from the other drift, they contain rather more erratics than the other gravels of this valley, and thus more closely resemble the 'erratic' gravels of the Lower Worfe.

It follows, if the above views be correct, that the sands and gravels of the Upper Worfe and the Tong Brook belong to a late stage in the Glacial retreat, but to one before the ice-front had actually receded to the north of the main watershed.

Unfortunately, we have no means of determining the exact relations of the retreat-positions VII–X in the Upper Worfe Valley with the earlier positions near Iron-Bridge; but it is clear that the Iron-Bridge overflow preceded, by a long time, the withdrawal of the ice across the watershed at the head of the Worfe. It was not until this had occurred that Glacial Lake Newport came into being. So it is evident that these outwash gravels must antedate by a long time the period at which the union of that lake with Glacial Lake Buildwas produced Glacial Lake Lapworth.

We see now the reason why the low part of the old watershed near Newport could not be brought into commission as the permanent overflow-line for the Upper Severn; for the Iron-Bridge Gorge was already acting for this purpose, and had by now reached a lower level than the lowest col at the head of the Worfe.

VII. Conclusion.

In conclusion, I would like again to record my indebtedness to Mr. E. E. L. Dixon for his friendly criticism, advice, and infectious enthusiasm, and to Mr. T. Robertson, Mr. R. W. Pocock, Prof. W. S. Boulton, my wife, and numerous other friends, who by critical discussion or by help in the field have assisted in elucidating the history of the Iron-Bridge Gorge and the Worfe Valley. The intricate nature of the problem far exceeds the expectations which I formed in 1914, and I fully realize that parts of the record deserve further attention, and may be modified by subsequent work. Especially is this so in the Worfe Valley, where the relation of the gravels to the other drifts is capable of other interpretations than those offered here. Nevertheless, the origin and growth of the Iron-Bridge Gorge, through a varied series of marginal phenomena related to the last Glacial episode of the Midlands, appear to be firmly established. Thus the broad generalizations of Lapworth and Harmer are shown to be correct; although it will be agreed that the complexity of the story exceeds anything that is suggested in their writings.

At some subsequent date, I hope to show in a continuation of this paper, how the connexion of the Main Terrace of the Severn with the melting of the Irish-Sea Glacier elucidates the history of the Lower Severn, and may help us to date and correlate events that are recorded in the gravels of other rivers.

EXPLANATION OF PLATES XXII & XXIII.

Plate XXII.

Geological map of the Iron-Bridge Gorge and the Worfe Valley, on the scale of 1 inch to the mile, or 1 : 63,360. B=Barrow Col, 630 feet O.D.; C=Coalmoor Col, 632 feet O.D.; D=Dean Corner morainic gravels; E=Echoes Hill; G=Grindle Gravels; GB=Gorsey Bank Col, 350 feet O.D.; H=Gravel-pit three-quarters of a mile south of Beckbury; K=Monk's Wood, south of Stanton; L=Lightmoor Col, 365 feet O.D.; LH=Lincoln-Hill Silts; M=Madeley Wood; MG=Mossey Green; N=The Grove gravel-pit, Bridgnorth; O=Oakengates Col, 470 feet O.D.; P=Posenhall Col, 595 feet O.D.; Q=Strethill; S=Smithies Col, 352 feet O.D.; W=The Wyke; X=Gravelly clay in Lightmoor Col; YY=Gravelly clay around Coalbrookdale.

Plate XXIII.

Fig. 1. Longitudinal section along the Severn Valley.
2. Longitudinal section along the Worfe and the Mad Brook.

[Both sections are on the horizontal scale of 1 inch to the mile (1 : 63,360) and on the vertical scale of 1 inch to 100 feet (1 : 1200). They show the relation of the drifts to the present and past thalwegs.]

Discussion.

The Secretary read the following communication, received from Mr. E. E. L. Dixon:—

'Having had the pleasure of going over much of the ground with the Author, and the privilege of reading his results and conclusions, I should be glad to be allowed to contribute to the discussion.

'In my opinion, he has completely confirmed the truth of the explanation of the Iron-Bridge Gorge, suggested, independently one of the other, by Lapworth, Kendall, and Harmer. But he has done much more: he has shown that the initiation of the gorge was part of a continuous story, an incident, in fact, in the retreat of the Irish-Sea ice-sheet from the Midlands. By means of that feature and others impressed on the topography, and by means of the Glacial deposits, he has traced the retreat from the presumed front of greatest extension, pause by pause, back to the Wrekin.

'We may be sure, now, that we know from the Author's work the general lines of the retreat. Being aware of his intimate acquaintance with the ground, I would venture to suggest alternatives in only one or two matters of detail. He is confident that the pre-Glacial Worfe drained westwards at its present mouth into the Severn. Consequently, there is no need to suppose that this outlet from the Worfe Basin to the Severn is a marginal channel cut while the ice-sheet still lingered in the eastern part of the basin, and closed the low outlet by the Claverley Brook to the Stour. But the sharp bend to the south-west of the Worfe near its mouth, parallel to a notch in the Bunter ridge at Pendlestone Rock close by, suggests that at one stage the ice-margin ran in this direction hereabouts. That is, after Stage II, while still lying along the north-and-south Bridgnorth reach of the Severn, as in Stage II, it left the Severn north-eastwards at the Worfe confluence. Its further course at this period may have been along a tributary of the Worfe, in line with the south-westerly bend, and on to Merecot and the marginal position, evidence of which is furnished by the Echoes-Hill gravels.

'I would also ask the Author whether the undoubted difficulty in supposing that the Oakengates overflow drained down the Mad Brook may be removed by supposing that the ice-front in the earlier part of Stage VI lay across the Mad Brook and along the Coalport Brook to the Severn. (The latter brook may have functioned also at Stage IV.)

'The successive positions of the ice-front undoubtedly show the influence of two ice-streams in the Irish-Sea ice-sheet, the one pouring from the west over the high plateau between the Wrekin and Wenlock Edge, and the other, in much greater volume, from the north across the lower watershed east of the Wrekin. The latter stream pressed westwards, as well as southwards, where clear of the watershed, and confined the marginal drainage within the ground rising westward towards the Wrekin and the Barrow-Broseley plateau. In this tendency of the ice-sheet at the various stages of its retreat to rest with its front up against rising ground, it has behaved like the retreating Scottish ice in the Carlisle district.

'The observations made by the Author in connexion with the rejuvenation of the Severn and the cutting of the lake-outlet below the 300-foot level appear to point to isostatic adjustment. It will be important, therefore, to ascertain whether the strand-line shows warping when traced northwards. The Author, by his painstaking study of a large area and his careful separation of inference from observation, has laid a firm foundation for future work.'

Prof. W. W. Watts desired to congratulate the Author on the completion of a very difficult investigation, and to compliment him on the skill with which he had presented the evidence for the solution of so many complicated problems to the Society. The speaker had been much interested in the Severn Gorge since hearing

the late Prof. Charles Lapworth put out his beautiful theory, rather as a suggestion for work by other geologists than as a completed study; but, as was usual with that geologist, with more evidence in his mind than he thought necessary to reveal. Consequently, the speaker had given some attention to the superficial geology of the Gorge region when assisting students to map part of the ground mainly in relation to its 'solid geology'.

The 'Buildwas Sands and Gravels', with local, northern, and probably Welsh erratics, spreading up the valley to Shrewsbury and beyond, and over much ground towards Church Stretton, certainly suggest the existence of a Glacial lake held up by the unpierced bar of Benthall Edge–Lincoln Hill. But this deposit rests on the existing topography: its base is not shown at 150 feet O.D. at Buildwas Station, and a record probably still exists of a considerable sinking into it below this level. It is at 200 feet O.D. at Buildwas Abbey, 300 at Strethill gravel-pit, and considerably higher to the west of it, at over 300 feet along the Wenlock railway in Farley Dingle, while apparently similar material was discovered in Benthall churchyard at over 600 feet, and it was described by Maw at Ryden Hill (probably the knoll half-way between Benthall Hall and Wyke) at 600 feet and over. The dissection of the country immediately above the entrance of the Gorge, and, above all, the production of the scarp of Benthall Edge and Lincoln Hill are evidently related to the levels inside the Gorge; yet the gravel rests on that topography. The speaker could not understand how this topography could be produced at the headwaters of such slack streams as would be caused by the slight difference in level of the apparent base of the gravel at Buildwas and that at the embouchure of the Dee below Llangollen. Further, the 35 species of marine shells determined for Maw by Gwyn Jeffreys, several of which seem to have been quite perfect, need some explanation, even though the chief locality is inaccessible and the collection seems to have been lost. These two difficulties were not dealt with in the Author's abstract. nor had they been alluded to in his presentation of his case, and the speaker ventured to hope that they would receive some consideration in the Author's reply.

Mr. R. W. Pocock suggested that the deep erosion of the Buildwas area was effected during the advance of the ice. The confluence of the Welsh and Irish-Sea ice along the line Ellesmere-Baschurch–Wrekin would have produced great pressure in the angle between the Wrekin and Wenlock Edge, and would have scoured out the soft Wenlock Shales in overriding the high ground on the east.

He remarked on the coincidence in the levels of the Buildwas and Newport lakes; he thought that they were but inlets of a large lake covering the North Shropshire Plain, as he had traced the strand-line at the 300-foot level, just described by Mr. E. E. L. Dixon, over much of that area. The lake was probably held up on the north, not by ice, but by the morainic belt extending from Oswestry through Whitchurch to Market Drayton, and

it would have persisted long after the retreat of the ice from the district.

Mr. T. H. Whitehead remarked that, as noted by Harmer, it was essential that any theory of the origin of the Iron-Bridge Gorge by overflow should take account of the blocking by ice of the outlets over the lower parts of the watershed near Newport. In this connexion, the evidence adduced by the Author & Mr. Dixon for the persistence of the ice-front in the Upper Worfe Valley until after the Iron-Bridge gap had become established was of importance. The speaker drew attention to the deposits of sand lying on the northern slopes of the watershed from Ketley to Wormbridge, at heights up to about 350 feet O.D. These were perhaps laid down in a marginal channel between the ice-front and the rising ground on the south. That the ice-front at the time of their deposition was not far away, and that advances of it took place subsequently, is suggested by the fact that these sands are in several places overlain by boulder-clay.

The Author, in reply to Prof. Watts, pointed out that the pre-Glacial Dee Valley was at present buried deeply in drift; and that possibly this fact would remove Prof. Watts's difficulty about the gradient from Buildwas to the former confluence with the Dee. Personally, he had never found more than chips of marine shells, though such were present in all the sands of the district. He had regarded them as boulders.

Referring to the remarks made by Mr. Pocock and Mr. Whitehead, he pointed out that the occupation of the Newport Col by ice at a late stage in the retreat seemed firmly established; and that, in any case, there was no good evidence that it had acted as an overflow-channel from Lake Newport. At one time, this lake drained into the Trent at 309 feet O.D. near Gnosall, whereas the Newport Col rises to about 350 feet O.D.

12. *The* GEOLOGY *of the* NORTHERN BORDER *of* DARTMOOR *between* WHIDDON DOWN *and* BUTTERDON DOWN.

By CHARLES WILLIAM OSMAN, M.Inst.C.E., F.G.S. (Read December 5th, 1923.)

[PLATE XXIV—MICROSCOPE-SECTIONS.]

CONTENTS.

I. INTRODUCTION.

IN this paper the Lower Carboniferous formation bordering the granite of Dartmoor for a length of about 4½ miles, between Whiddon Down on the west and Butterdon Down towards the east, are the only stratified rocks dealt with; but the nature of, and variations found in, the granite south of the Carboniferous rocks are also considered. The area examined includes part of the deep gorge of the River Teign, known as Fingle Glen, between Hunter's Tor and about a mile east of Fingle Bridge, or rather more than two-thirds of the length of the gorge.

The area described is covered by the 6-inch Ordnance Survey quarter-sheets of Devon:—LXXVII, S.E.; LXXVIII, S.W.; LXXVIII, S.E.; XC, N.W.; and XC, N.E. Of these quarter-sheets only the whole of LXXVIII, S.W. is covered; but portions of the other sheets are required to describe the area in a comprehensive manner.

II. BIBLIOGRAPHY.

Comparatively little appears to have been written concerning the precise area discussed in this paper, but references to portions may be found in the works enumerated below.

The references to these publications will be given in the text by the numerals in parentheses in the following list set against the respective papers.

(1) 1839. Sir HENRY T. DE LA BECHE. 'Report on the Geology of Cornwall, Devon, & West Somerset' pp. 118, 122.

(2) 1867. G. W. ORMEROD. 'Notes on the Geology of the Upper Teign & its Feeders' Q. J. G. S. vol. xxiii, pp. 418, 424, 425.

(3) 1867. G. W. ORMEROD. 'Carboniferous Beds adjoining the Northern Edge of Dartmoor' Trans. Devon Assoc. vol. ii, p. 124.

(4) 1888. W. A. E. USSHER. 'Granite of Dartmoor' Trans. Devon Assoc. vol. xx, pp. 141 & 149.

(5) 1894. C. A. MCMAHON. 'Notes on Trachytes, Metamorphosed Tuffs & other Rocks, on the Western Flank of Dartmoor' Q. J. G. S. vol. l, p. 338.

Geological sketch-map of the
on the scale of 1·8 inch

Cut line

rthern border of Dartmoor,
the mile, or 1/35200.

line

(6) 1902. R. H. Worth. 'The Petrography of Dartmoor & its Borders: Part I' Trans. Devon Assoc. vol. xxxiv, p. 496.
(7) 1906. A. W. Clayden. 'The History of Devonshire Scenery' p. 48.
(8) 1912. 'The Geology of Dartmoor' Mem. Geol. Surv. (Sheet 338) pp. 35, 39, & 46.
(9) 1913. 'The Geology of the Country around Newton Abbot' Mem. Geol. Surv. (Sheet 339) p. 104.
(10) 1919. R. H. Worth. 'The Geology of the Meldon Valley near Okehampton, on the Northern Verge of Dartmoor' Q. J. G. S. vol. lxxv, pp. 77 & 89.

III. The Stratified Rocks.

In the area dealt with, the Lower Carboniferous, or Culm Measures, may, as found by Mr. R. H. Worth (10) in the granite-border south-west of Okehampton, be divided into two groups: the Lower Aluminous Series and the overlying Calcareous Series. Both these series of rocks have been affected by contact-metamorphism from the granite.

The Lower Aluminous Series in this district can be divided into zones: the lower zone characterized by the occurrence of much segregated or disseminated iron-pyrites, and the upper zone in which chiastolite is found.

The Lower Aluminous Series passes upwards by gradual change, and without any physical feature, from black slates into brown shales of the Calcareous Series, in which occur impure limestones. These limestones are confined to an area east of Whiddon Down (1); and another area characterized by black limestones, from half-a-mile east of Drewsteignton Village to about a mile away to the west. The top of the Calcareous Series is well defined by a steep northern slope (or escarpment) due to its greater resistance to weathering, overlooking the Middle Carboniferous, or Upper Aluminous Series; and, as these latter rocks extend for some considerable distance northwards, it would be beyond the scope of a single paper to deal with them, although their southern margin is, in places, well within the metamorphic aureole of the granite.

IV. The Granites and Igneous Rocks.

The granite area south of the Carboniferous rocks, although derived from the same magma, is varied, and constitutes three different types:—

(i) The country-rock granite G.—This granite, which was the main intrusion of the district, consists of large orthoclase-phenocrysts, closely packed together, with evident flow-structure, in a small amount of coarse ground-mass.

(ii) Secondary intrusions and dyke-granite, G1.—After the main country-rock granite had consolidated, but was still hot, a further movement occurred which broke up the original granite G, and into the joints and spaces thus made, a newer granite rose, forming dykes and irregularly shaped areas, which appear to overlie the country-rock granite G. Its phenocrysts of orthoclase are fewer and smaller, while the ground-mass which forms the

greater proportion of the rock is finer, and contains frequently less orthoclase than plagioclase.

(iii) The fine-grained granite G 2.—Further movement was followed by the incoming of a still finer granite, which usually occurs in veins, sills, and small dykes, locally called, incorrectly, elvans. But also on the north-west, south, and east of Cranbrook Castle Camp, as far as Butterdon Down, this granite made a considerable marginal intrusion, faulting and lifting up the Culm rocks and overlying the previous granites.

(iv) Other igneous rocks.—A thick bed of cherty ash, and leucocratic rock-breccia, with the characteristics of a keratophyre, occurs in the Calcareous Series of the Lower Culm at East Underdown Farm, and is seen in the well by the roadside.

V. Field Relations.

Near Whiddon Down no exposure of the Lower Aluminous Series occurs, and the junction with the granite is not seen, owing to the accumulation of marshy wash (4); but this can be approximately fixed by the steeper slopes of the Aluminous Series. A little more than a quarter of a mile south-east of Whiddon Down are two ancient quarries known as Mill and Hobhouse Quarries; they are thickly overgrown with trees through long disuse, and are both in the Calcareous Series. They are considered to have been commenced over 200 years ago, and were worked for lime which was mainly used for the land. Both quarries are very large, and show the same features, so a description of Mill Quarry will suffice (as being the clearest). This is about 400 feet long by 150 feet in width, and more than 80 feet deep. Trees, shrubs, and talus hide most of the quarry; but an adit driven through the south-western side keeps it drained and accessible, and some good exposures can be seen. The rocks are greatly disturbed; the southern side and middle show dips of 75° down to N. 200° E.; while in the northern half the same rocks dip to N. 45° E. between 30° and 40°; the general trend of the junction being N. 104° E. This is a case of underthrusting and uprearing, due to the Calcareous Series slipping up the syncline on the Aluminous Series below. The most abundant rock is a crushed black shale, in which are many bands from 6 inches to 2 feet thick, of impure grey and brown limestones, sandy layers, and chert-bands up to 8 or 10 inches in thickness.

The junction of the upper surface of the Calcareous Series with the Upper Aluminous Series runs in a general south-easterly direction from Whiddon Down to Hobhouse Farm buildings; but, about 100 yards beyond this farm, it is cut by a fault. The uplift is on the south-east side, and, as can be seen in the quarry on the Exeter road, a large amount of fault-breccia has been made. Through this and the minor slips pneumatolysis has been very active, so that the Lower Carboniferous rocks are locally very different from those on the north-western side of the fault, as described in Mill Quarry.

The Calcareous Series can be well seen in two quarries on the top of Natton Hill, about 330 yards south-east of Natton Hole Farm. All the rocks are green or greenish-grey, and their bedding and general aspect are similar to those observed in the rocks at Mill and Hobhouse Quarries, but their condition is very different. The cherts and fine shales are here calc-flintas, and the poor limestones axinite-pyroxene-schists.

Between Silkhouse Farm and Parford two parallel faults, well indicated by the Ordnance-map contours, have brought the granite higher up than on either side; and between them the Lower Aluminous and Calcareous Series have been flattened, so that they show broader outcrops than in the north-west. There are no quarries between the two faults, but several road-surface and side-cutting sections can be seen. East of these faults the Lower Culm outcrop rapidly widens out, with much flattening of the true dip; but the compression-jointing becomes more acute, and this sharp-angled jointing continues to beyond Cranbrook Castle Camp.

Outside the bend in the Chagford-Drewsteignton road, a little over a quarter of a mile east of Parford, Coombe Farm Quarries are situated. The two southernmost (Nos. 1 & 2) show G 1 granite only; but the two on the north-east show the Lower Aluminous Series. In the lower quarry (No. 3) an excellent junction of the Culm with the granite can be seen. At a little less than 660 yards away to the north, along the Drewsteignton road, is the large Wisedom Farm Quarry, partly in the chiastolite-zone of the Aluminous Series. The chiastolite is confined to certain bands; but the whole of the rock is so broken up that these cannot be traced on the quarry-face. Chiastolite, is, however, more easily found at the northern end. With these bands are associated hornfelses and quartzites. Also, many pneumatolytic quartz-tourmaline-veins occur.

The deep, narrow gorge of the River Teign, generally known as Fingle Glen, is a remarkable piece of Nature's handiwork. The whole of the northern slope, as far as the eastern end of the map (p. 317), is in the pyrites-zone of the Lower Aluminous Series: also, the southern slope is mostly formed in the same beds; but they are not continuous throughout, being broken by an outcrop of G 2 fine granite. The rocks of the Lower Aluminous Series have been intensely hardened and metamorphosed; they are much faulted, and show compression-jointing varying from 10° to 50° on the bed-joints. The Culm is veined by the granite: the largest vein, about 80 yards from the west side of Sharp Tor Rocks, is some 30 feet wide at the bottom on the north side of the gorge. This bifurcates at about the level of the 600-foot contour.

The G 1 granite-dyke of Hunter's Tor continues across the River Teign into the Lower Whiddon Deer Park, and forms a buttress to hold up the Culm on the steep slope above the Forder Brook; and, generally speaking, the whole of the area from the south of Fingle Glen to the south of Cranbrook Castle is much

complicated by faults, as also by the large intrusion of fine-grained granite G 2. The first of these faults is that which runs in a north-easterly direction from near Forder to the west side of Sharp Tor Rocks in Fingle Glen. The second fault is parallel to the above, and runs from Uppacott, by the flank of Prestonbury Common, to about 400 feet east of Burrough Farm. These faults shift the dyke south-westwards for a short distance in Whiddon Park and at Uppacott. Small slip-faults terminate these diversions with numerous springs, while the dyke continues in its original south-easterly direction, and can be seen in the bend of the road at Linscott Cottages, at the southern margin of the map (p. 317).

On both sides of the Teign, from Coombe Farm Quarry to the Sharp Tor-Forder Fault, the north-east side of the great dyke abuts on the Lower Aluminous Series of the Carboniferous rocks; and there can only be a very short length (if any) of granite in the bed of the Teign itself, north-east of the crossing of this dyke at Hunter's Tor. The bed of the river and its banks are so cumbered with large blocks from the dyke that it is impossible to see exactly of what it is composed, and a quarry immediately above the river-bank in Whiddon Park, opposite the first island, is in the Lower Aluminous Series. South-east of the Sharp Tor Fault in Whiddon Wood the top of the slope, both inside and outside of the Deer Park, as far up as the 900-foot contour, is G 1 granite similar to the dyke; but very soon the Lower Aluminous Series again comes on against the dyke. This continues to the fault south-east of Uppacott, where country-rock granite G once more appears for a short distance, and is overlain by the fine granite G 2 against the G 1 dyke south-east of Linscott: this is in turn overlain by the Lower Aluminous Series south of Cranbrook Castle Quarry.

Let us return to Fingle Glen. It has been mentioned that the south side does not show a continuous section of the Lower Aluminous Series, as Ormerod (2) states; but a considerable area in Whiddon Wood is fine-grained granite G 2. Not only is this the case, but also the river-bed below Sharp Tor Rocks is in the same granite, and this can be seen to underlie these rocks nearly up to the 500-foot contour on the north side. On the south side this granite can be followed through Whiddon and Hannicombe Woods as far as Uppacott Down; and, as the slope of the gorge is ascended, the outcrop of fine granite widens to over half a mile on the Down above. The whole of this area is covered with more or less rounded blocks of G 2 granite, until the edge of the Culm is met north-west of Cranbrook Castle Camp. It is rather surprising that this fine granite has not been noticed before, especially as the quantity of large stones weathered out of the exposure has been amply sufficient to provide the bulk of the granite roadside and field-walls from Linscott on the north and east, including the main length of Whiddon Deer Park north-eastern wall; and above this, the clearing of the land has necessitated the piling up of huge heaps in field corners, and a ridge 200 feet long near Whiddon Deer Park wall.

The junction of the Lower Aluminous with the Calcareous Series probably extends from Bowden Farm to south of Cross Farm, thence to the north of Shute Down Coppice, and along the north side of Cross Farm Brook to its confluence with the Silkhouse Stream.

In the lane east of Drewsteignton Church, leading to the fields, the black limestone crops up at several places in bands in brown shales; and in the large square field between the lane and the road to Fingle Glen, the limestone terminates abruptly at a marked change of slope—apparently a thrust-plane. The base of the limestone is not clearly marked west of the church, and, probably, after crossing the Rectory grounds, it passes north of the school, trending north-westwards, a little south of the great quarries, and finishes north-east of Bowbeer Farm.

The top of the Calcareous Series and junction with the Upper Aluminous Series is formed of black shales and thin, hard, grey rock-bands, at the foot of the escarpment facing northwards from Drewsteignton to East Underdown Farm, although it is locally concealed by the great tips of waste from the quarries.

Between the sudden eastern termination of the Drewsteignton limestone in a north-east by east direction, and the Prestonbury Camp fault, is an area of great crush, and the horizon of the limestone is occupied by a ridge of sheared and pneumatolysed hard crystalline rocks, which can be seen in field exposures on the ridge north of Drewston House. The Calcareous Series, east of the Prestonbury Fault, shows a more regular arrangement of the rocks on the north side of a sharp monoclinal fold, which continues westwards, and appears to die out at the East Underdown faults. In the Prestonbury and Broadmoor Commons area, the black slates of the upper beds of the Lower Aluminous Series pass into grey shales of the Calcareous Series, in which occurs a chert-band. Out of this huge nodules of altered chert have weathered, and rolled down the slopes. On the north, lying above this band, the grey shales continue for a short distance, and pass into buff-coloured, fine, sandy rocks with iron-stained joints, on the horizon of the limestone: these again pass upwards, by grey shales and hard rock-bands, into the Upper Aluminous Series, but no limestones have been found.

The country-rock granite G south of Whiddon Down forms a large area from the Blackaton Brook beyond the map on the west, which on the east is bounded by an irregular line from the Teign through Sandsgate to near Bradford Pool. This area is slightly undulating, with a general northward rise.

The Rushford Wood intrusion of G 1 granite appears to be a large complex of dykes and sills overlying the G granite, and runs generally in a north-north-westerly direction from the south of Rushford Tower.

The portion of the granite-mass that lies between Sandsgate and Bradford Pool is capped in its highest part by blocks of a fine-

grained or G 2 granite, about 400 yards from north to south. In the field north of this, near Shilstone Farmhouse, is the well-known 'Spinster's Rock' cromlech, formed of three big upright stones and a capstone weighing about 16 tons. All these four stones are of typical G 1 granite.

The Rushford Wood granite ends northwards in a dyke, about 20 feet wide, and is seen in the hedge in the fields between Tordown Farm and East Tordown: this dyke has penetrated both the G granite and the Lower Aluminous Series, blocks of granite being found on the latter rocks (4). The irregular spur on the east at the southern end of the Rushford Wood G 1 granite-intrusion forms the Dogmarsh Wood cliff and also the hill north-west of Highbury House. The Teign in crossing this hard granite between the above two positions, has formed a small gorge, with many hard granite-blocks and small islands in the river.

A little more than 100 yards south-west of Sandy Park Mill House is a quarry showing a face of aplite about 140 feet long, and about 20 feet in greatest height. The middle portion of the face consists of felspar and quartz only; but, at both ends, tourmaline-nests appear in the rock. Strong master-joints striking north 10° east, with a nearly vertical westward dip, are the principal feature indicating the direction of the dyke; and, with the aid of these, the rock can be traced northwards by well-marked ridges in the bed of the Teign.

The north-western visible end of the Hunter's Tor G 1 granite-dyke underlies the Carboniferous rocks on the west side in a thick sill, the remains of which lie above the G granite in an irregular area, extending southwards to, and on the south side of the Teign, forming the bluff of the wood west of Whiddon Park House. A similar sill of the dyke on the north-eastern side, but at a higher level, accounts for the small patch of G 1 granite seen between the 750- and 900-foot contours in Whiddon Deer Park, which underlies the G 2 fine granite.

An extraordinary exposure of the country-rock granite G is to be seen in the south-eastern end of Whiddon Deer Park, near the line of the G 1 granite-dyke, at a height of about 760 feet, where a small crag *in situ* stands up boldly above the general level of the land. This rock is crowded with the usual orthoclase-phenocrysts, but has been tourmalinized, and the now reddish felspar pneumatolysed to such an extent as to enable it to resist weathering.

Willingstone Rock is part of a big G 1 granite-dyke in the Lower Aluminous Series. It is about 30 feet above the ground surface at its highest part, and strikes on the flat north side north 80° east with a steep northward dip. It is difficult to account for its presence here, except on the assumption that, when the G 2 granite lifted up the Culm rocks, this dyke was sheared across and raised up with the Culm.

The field relations of the fine-grained granite (G 2) large intrusion have generally been dealt with in the course of the description

of Fingle Glen and the area immediately south thereof, and I need only further remark that, if we judge from the amount of the flattening-out of the overlying Carboniferous rocks, it must be in places several hundred feet thick. But I may mention that, as similar G 2 granite-veins and sills are found in both G and G 1 granite, the intrusive fine-grained granite G 2 must be more recent than either; and that, generally, the smaller the thickness of a vein or sill, the finer is the grain of its constituents.

VI. Petrological Details.

It is not to be expected that the Carboniferous rocks of the Dartmoor northern border can be very different from the same rocks south-west of Okehampton described by Mr. R. H. Worth (10), and by the Geological Survey (8 & 9) on the south and east. Still, although the rocks are generally similar, variations occur, and these are worthy of record. Also great local pneumatolytic action has made differences in the rocks that do not appear in the areas above mentioned. Some of these may be due to the separate granitic intrusions superinducing pneumatolysis on rocks that had already been contact-altered.

The lowest Carboniferous rocks of the Dartmoor Granite northern border appear to have originally been a series of thinly-bedded or laminated sands or loams; these near Whiddon Down seem to have had generally a more shaly character, and to become more banded with sands at Cranbrook Castle towards the east.

(i) The Lower Aluminous Series.

Some of the lower beds of the Lower Aluminous Series to be seen at the southern end of Cranbrook Castle Quarry are sericite-chlorite-hornfelses, with numerous segregations of iron pyrites and remains of a little felspar. The sericite is often in radiate tufts, and brown tourmaline flecked with blue occurs in plates measuring up to 2 mm. in longest diameter. The chlorite contains haloes, which disappear on rotation and may be altered biotite. Andalusite appears only to occur in association with the small granite-veins found in the rocks. In the middle part of the quarry these hornfelses pass up into banded quartzites of the same general character, with small rutiles; and, as the higher beds at the northern end of the quarry are reached, they pass into light and dark-banded tourmaline-quartzites.

At Coombe Farm Quarry (No. 3), in the steep Lower Culm face, left on the east side by quarrying away the G 1 granite-dyke, andalusite-hornfels occurs. The andalusite-crystals attain 2 mm. in length, and show pink pleochroism; the ground-mass is crypto-crystalline mica, felspar, and quartz, studded with biotite-crystals mostly decomposed, about 1 mm. long, and there is a considerable amount of iron pyrites. In Coombe Farm Quarry (No. 4), fine grained hornfelses are found containing small quartz, tourmaline and sphene-veins (Pl. XXIV, fig. 1).

In Wisedom Farm Quarry both the sericite-chlorite-hornfelsed rocks and the chiastolite-schists are found. The sericite-chlorite-hornfelses are fine-grained, and the rocks are spotted, the chlorite with haloes generally forming areas in a quartz-sericite ground-mass. Pyrites and rutile are still abundant, but some slides show a greater amount of fine quartz-grains. These rocks pass upwards into banded schists of chlorite with haloes, between layers of quartz-sericite with less pyrites. These schists, where pneumatolysed, became banded quartz-tourmaline-schists. Cordierite-hornfels has only been found, at Wisedom Farm Quarry, in rather narrow bands in the hornfels, and is of the ordinary type occurring around Dartmoor. The chiastolite-zone is well developed here, and every gradation from the fresh mineral, through bright yellow to complete decomposition, can be found. The Dartmoor border cruciform chiastolite in dark slates is well known, and is described and illustrated in the Geological Survey Memoir (8). The rock of the northern border, however, as at Wisedom Farm Quarry, is not a slate, but in all respects a hard schist, forming the principal source of road-metal for the neighbourhood. Owing to the complete series from fresh to decomposed chiastolite found here, this zone can be traced nearly to Whiddon Down. It is curious that, even when much decomposed, traces of the right-angled chiastolite cleavage may be seen with a lens on a freshly-fractured surface, although nothing but a mottled mica-and-quartz-rock appears in a thin section.

The black slates forming the top beds of the Lower Aluminous Series are only seen in the eastern part of the area, where they can be traced from Broadmoor Common, to Shute Down Coppice, near Cross Farm, or rather more than a third of the length of Dartmoor Granite border under consideration; but as, where seen near the latter place, they are well developed, there can be little doubt that they are continuous throughout. These slates vary much: in some places they are hard and splintery, while at others they are soft and fissile. They are chiefly ordinary fine-grained quartz- and mica-slates, and show a depolarizing ribbon. Some are banded with fine sands, now quartzites, and, at the junction of these, small zircons may sometimes be found in the sands. The passage up into the Calcareous Series is conformable by gradual change, and the division-line shown on the map (pp. 316–17) is merely an arbitrary one.

(ii) The Calcareous Series.

The base of the Calcareous Series is formed of shales appearing brown through weathering; but, when the pieces are sufficiently sound to be split, they are dark grey inside, and it is only when these shales cease and volcanic fragments with chert, slate, and ash are found, that a definite horizon is reached.

These mixed and volcanic rocks are a portion of a very long series of bands around the north and north-west of Dartmoor, and south and west of Okehampton have been variously described as

'trappean rocks' by De la Beche (1), 'metamorphosed tuffs and trachytes' by McMahon (5), and as 'dark igneous rocks' by Mr. R. H. Worth (10). In all the specimens showing volcanic fragments, however, and in all thin sections hitherto seen, though the perthitic felspar is not much affected, the ground-mass has been greatly altered, and its true character obscured by secondary fine biotite and infiltration of chert, as well as by pneumatolytic alteration, so that the rocks have been darkened. In some of the freshest thin sections, traces of the trachytic character of the volcanic fragments remain; but such traces are the exception rather than the rule. In some cases, the alteration has been so great that these rocks have been described as cordierite-hornfels, and have developed radiate anthophyllite; but even these show the structure of the perthitic phenocrysts, although, of course, they are much altered.

In this area the volcanic rock appears to be more solid and less altered than anywhere else at the East Underdown Farm well, 20 feet deep, against a roadside cutting about 16 feet deep. The rock is nearly white, with dark-green specks, stained yellowish brown on its joints, and fairly fresh pieces of large size can be obtained. Sections of these show perthitic phenocrysts in a typical ground-mass of tufted radiate albite-oligoclase; a few small spots of secondary biotite occur, also a little chlorite, and some garnet. This rock is a quartzless keratophyre. As in the same neighbourhood, from the field stones on the top of the ridge, specimens of light and dark rock of the same nature show in sections made from them the darkening to be due to later cherty infiltration, with biotite contact-alteration; and as also the same dark rock, but weathered, can be found near by in the field exposure, mixed with slate, other fragments, and chert, it would appear highly probable that the Meldon 'dark igneous rocks' are the representatives of the East Underdown type of keratophyre and mixed rocks. Partial pneumatolytic action on the East Underdown well-rock changes its whiteness to mottled green; and in thin section, the altered keratophyre shows small areas of new clear felspar with blue tourmaline-prisms and some chlorite-crystals. These areas are surrounded by fine biotite alteration, while the tufted albite-oligoclase ground-mass has become fainter in its structure (Pl. XXIV, fig. 2).

East of the East Underdown parallel faults, the volcanic horizon can only be traced by surface-stones on cultivated land, following the limestone in an east-south-easterly direction, becoming more cherty as it goes eastwards, until the band dies out a little east of Drewsteignton. Farther east, the volcanic-band horizon at Prestonbury and Broadmoor Commons is generally represented by blocks of segregated cherty rock, which weather out and roll down the slopes. These are very hard, tough, and weather-resisting. In thin section, they show mostly chert with a matt of incipient fine tourmaline-crystals, in which occur clear

quartz-areas and veins, with well-formed pale tourmaline, frequently a little diverging, and of slight pleochroism: the triangular cross-sections extinguish in segments of three triangles. Or they are cherty quartzites with quartz-tourmaline-veins, in which an occasional grain of tinstone occurs. The volcanic band also thins west-north-westwards, and, from the south of Whiddon Down to the Tordown Fault, it is represented by ashy chert-rocks, only found in field stones, south-west of the limestone quarries.

Between the Whiddon Down and Drewsteignton limestone areas, the shales above the volcanic band pass upwards into white quartz-veined dark quartzites, seen in the road-exposures south of Silkhouse Farm towards East Underdown. These quartzites pass upwards into the grey shales with hard blocky rock-bands, and so into the Upper Aluminous Series.

The Whiddon Down limestone area extends from west of the Old Toll House to near West Underdown. The lowest brown limestone seen in the Mill Quarry black shales consists of white garnet in a hazy ground-mass of calcite and fine quartz-grains; veins of calcite and a fibrous mineral traverse the rock: the fibrous veins being across the bedding, are perhaps due (in the first instance) to original shrinkage. The immediately succeeding limestone-bands are similar garnetiferous rocks, but idocrase also occurs; the ground-mass becomes more cherty, and the cross-bedding shrinkage-cracks are filled with idocrase, chlorite, garnets of good crystalline form, and a little quartz. Still higher up, the limestone-bands become grey, more blocky, and consist mostly of calcite, with some small amount of cherty infiltration, and the veins are irregular and filled with calcite. An interesting grey limestone from the lower part of Hobhouse Quarry shows a clear calcite ground-mass with macled crystals of axinite and some asbestos, and a little pyrites and chlorite. Interbedded with the limestones and black shales are finely-banded cherts, much brecciated, and with high double-refraction chlorite and quartz-veins.

East of the Tordown Fault the lime-bearing rocks of the Whiddon Down area show a limuritic change, and are pneumatolysed; and, although somewhat similar rocks have been described from the west side of Dartmoor, they are altered spilites (8), and are not from the bedded Culm rocks. A little way east of the fault, pieces of rock can be found, consisting of fairly large incipient garnets, set in a ground-mass of green pyroxene.

The Natton Hill quarries show the greatest amount of alteration, and it is possible that these lime-bearing rocks were at first contact-altered by the granite intrusion, and that afterwards, while still very hot, the highly-heated pneumatolytic gases given off from the cooling granite produced entire recrystallization; also, that this took place while the rocks were in a solid condition is evident, as in thin sections their original lamination can be plainly seen, although the recrystallization is not in any way affected by it. As the only boric mineral found is axinite, it may be assumed

that water vapour and carbonic acid had a great deal to do with the pneumatolytic change.

The Natton Hill rocks, though all are banded, can be divided into three classes: the pyroxene-felspar-axinite crystalline schists; the pale grey-green calc-flintas with conchoidal fracture; and the finely granular porcellanites. The pyroxene-schists vary in size of grain; when fresh they are of a rather dark green, with violet axinite-veins: these schists weather to a bright yellow-green. The axinite exhibits pale-blue pleochroism in sections parallel to the Y axis. All sections show areas of greenish-brown carbonates, largely siderite, and generally a few crystals of sphene. In some slides, the ground-mass is nearly all very fine-grained felspar, a little decomposed, in such wise that by incident light a faint white suffuses the surface. As the refractive index of this is less than that of Canada balsam, it is probably albite; the remainder of the ground-mass shows streaks of axinite and a little idocrase.

The calc-flintas are cherty rocks, with many minute semi-opaque inclusions, which are white by incident light, and also contain granules of augite. In parts of the slide the pyroxene-granules are densely packed together, and these, between crossed nicols, exhibit an oriented crystalline structure.

The porcellanites show a granular ground-mass of chert with semiopaque inclusions, and in this are numerous oriented incipient crystals of augite, so that, between crossed nicols, the section has a resemblance to the schists. In this section is a well-marked vein of scapolite and some augite (Pl. XXIV, fig. 3). The vein-stones of these rocks are usually of axinite, deep violet in hand-specimens; sometimes the axinite is in eutectic growth with fairly large augite-crystals. Less frequently the veins are green diopside, and occasionally they are made up of well-formed colourless or pale-grey scapolite-crystals.

The Drewsteignton limestone area is well known: G. W. Ormerod (3) has described the great quarry, and little need be said here. The black limestone-bands in shales are mostly found at the east-south-eastern end of the area; while the west-north-western end is nearly all black calc-flinta. The black limestones burn white, showing that the colouring matter is carbon. The limestone is much traversed in some parts by numerous veins of calcite, while in others the stone is free from these. Radiolarian remains are common as round or oval spots in thin sections, with a border more or less complete, in a ground-mass of impure calcite. Some of the black limestones are composed of discrete small calcite-crystals, surrounded by carbon particles and impurities, and with black irregular lines of the carbon, giving a streaky banded appearance to the section. An analysis of this limestone gave 62 per cent. of silica (7).

The crystalline calcareous rocks of the crush-area between the

eastern end of the Drewsteignton limestone and the Prestonbury Fault also show a limuritic change, and are somewhat similar to those of Natton Hill, in that they are largely pyroxene-rocks with some axinite, felspar, and a little garnet; but, on account of the crushing and shearing that they have undergone, a blue hornblende has been developed in minute rods. These are massed together along the shearing-planes, and it is rare that a few rods do not occur in the augite-crystals. The pyroxene-crystals are in allotriomorphic growth, and the effect of the crush has been to reduce these to aggregates of parallel rods. These rocks are well seen in the field exposures on the ridge, north of Drewston House (Pl. XXIV, fig. 4).

It has been mentioned in § V (on the field relations) that the eastern termination of the Drewsteignton limestone is a thrust-plane, and it is possible that the later intrusion of the G 2 granite, after the rocks of the crush-area had been contact-altered, superimposed the local hornblendic change and the coarse shearing shown by the rocks.

(iii) The Granites.

It has long been known that the Dartmoor and allied granites on the west differ in parts considerably in coarseness of crystallization. These differences have been regarded as indicating separate intrusions of the same magma. Three types have been described: outer granite, inner or finer granite, and fine-grained granite-veins and sills, or felsites. Where the second intrusions of inner granite occur in areas sufficiently large to show on the Geological Survey 1-inch map, they are coloured a deeper red; but it does not appear that any mapping has been done of the dykes and sills that must have accompanied the inner granite-intrusion, although it would generally seem from the position of the quarries that these yield the granite of best quality. The junctions of the outer and inner granites are frequently indefinite, and pass gradually one into the other, so that the boundaries have to be drawn according to the observer's judgment; but, at other places, the junction is a sharp one. It is with great diffidence that the separation of the G and G 1 granites is shown on the map (pp. 316–17), but there are many more dykes and sills than have been traced in the area. Another difficulty that has to be taken into consideration is the shattering and fissuring caused by the Middle Oligocene syncline (9), that crosses the area under description, from south-east to north-west, especially as the amount of crush is not the same throughout the width of the affected band, but forms overlapping longitudinal areas of great crush, separated by ridges or areas where the amount is less. The north-eastern side of the syncline follows the direction of the Forder Brook, crosses the Teign, and passes out of the area here described south of Whiddon Down. North-west of Chagford, the synclinal crush-area rapidly narrows, and the western boundary can be traced by the solid mass of Gidley North Park, Throwleigh, and south-west

of South Zeal and Sticklepath. In one respect, the boundaries in such an area are somewhat simplified by the fact that, the G 1 granite being harder than the G granite, the former resists the crush in places, and forms isolated, more or less solid exposures, quarries being sometimes opened in these. Thus, if we find a series of exposures and quarries that form a straight, or nearly straight line, it is safe to assume that these are along the course of a dyke. Also the margins of the different granitic areas can be similarly traced roughly in the same way.

Kaolinization of the granite has not occurred to a great extent; but, where it is found, both the G and G 1 granites have been equally affected. The principal areas of kaolinization in the district are Padley Common, Chagford, both G and G 1 granite; around Sandsgate, in the G 1 granite; and on the west side of the district, in the valley of the Blackaton Brook.

The G granite's chief characteristics are its large, Carlsbad-twinned, perthitic orthoclase-phenocrysts, sometimes exceeding 7 inches in length. These generally exhibit flow-structure, by the straight or curved directions in which their longest axes lie, and usually are closely packed together (though they rarely show actual contact) in a coarse ground-mass of plagioclase and orthoclase, with agglomerated quartz sometimes an inch or more in longest diameter; while the subordinate biotite is in small crystals, frequently grouped together in clusters. All the mica seems to be of one generation. Tourmaline is so much scattered in small irregular shapes throughout the ground-mass that it may be considered an original constituent; and, in addition to this, it forms quartz-tourmaline nests up to 6 inches in diameter (Highbury Hill road-cutting). Apatite in stout prisms and grains is fairly plentiful. While minute zircons cause haloes in the biotite, much larger zircons occur in the quartz and felspar, and show a banded structure with high polarization-colours. In common with the quartz throughout the Dartmoor Granite, and perhaps in this area more fully developed, the quartz shows abundant cavities of varying size. All appear to contain a bubble; others contain a bubble and clear cubic crystal, while some, of irregular shape, are exceptional in having two bubbles, large and small, and occasionally two crystals. Cavities of negative crystalline shape are very rare. Basic patches of the usual ovoid shape, with much biotite, are not uncommon; these are usually of fine grain, but are in a decomposed condition, and they readily crumble to pieces. Large xenoliths of coarser granitic grain are also found in a weathered condition. Both are described in the inclusions of the G 1 granite.

The secondary, or G 1 granite, although much less in quantity than the G granite, is, owing to its greater hardness, its durability, and the number of quarries that have been opened in it, far better known in the north-eastern part of Dartmoor as being 'The

Granite' rather than the G or first granite. The largest and best-known quarry is that north-west of Blackinstone Rock, east of the area here described, which is in typical G 1 granite. This is in every respect similar to the granite of the Hunter's Tor dyke, as seen in Coombe Farm Quarry (No. 3), and in the new quarry in Whiddon Deer Park. The G 1 granite is largely ground-mass, in which the perthitic orthoclase-phenocrysts, often in cruciform macles, are scattered; these are always Carlsbad-twinned. The phenocrysts vary in length from about 2 inches in some places to as much as $3\frac{1}{2}$ or 4 inches in others; but they are never closely packed together, their distance apart varying from about 2 to 6 inches and over. Frequently the smaller crystals show the greatest distance apart. In the ground-mass there are numerous smaller phenocrysts of oligoclase of good crystalline form, some being macles. The extinction on the central part of a crystal cut parallel to the *b* axis required a rotation of 8° on both sides, the refraction (Becke's method) being a little above that of Canada balsam, and about the same amount below that of quartz. The biotite, like that in the G granite, shows the ordinary, or first crystals, varying from 1 to 2 mm. in longest diameter, and in addition to this, and often thickly scattered in the ground-mass, are minute flakes and wisps, indicating two generations of this mineral. Also, similar flakes frequently show as zonal rings in the plagioclase. The quartz, moreover, often appears to indicate two generations: the first being rounded phenocrysts, frequently surrounded by a ring of the small biotites, and, after the crystallization of these micas, the quartz-phenocrysts continued growing in optical continuity until they joined up with the ground-mass minerals, so that the outer edges of the quartz must be secondary, and of the same age as the ground-mass quartz, perthite, and biotite (Pl. XXIV, fig. 5). Such a two-stage crystallization has been suggested for the normal granite south of this area (8); but in this locality it appears to be applicable rather to the G 1 than to the G granite. Cordierite seems to have been a primary mineral of the G 1 granite, for it occurs as an accessory in all sections in association with the primary biotite, usually decomposed as greenish pinite, in which traces of structure are sometimes seen; but, occasionally, in a rare form of advancing decomposition, showing the basal lamellar structure, and a clear colourless to bright yellow pleochroism (Pl. XXIV, fig. 6). The rarer accessory minerals are apatite, in short prisms, frequently of a very pale-blue colour; zircons in crystals of fair size up to 0·1 mm. in longest diameter, and minutely in the biotite. Tourmaline, brown and blue, and sometimes the dense dark-green variety, is only found in small nests of quartz and felspar, but not in the ground-mass as in the G granite. Fluorite occurs occasionally in druses and cracks in quartz; and a highly refractive mineral, with high double refraction, suggesting monazite, is seen in some sections. Occasionally, ill-formed sphene, and rarely (doubtfully) a colourless allanite, may be observed associated with the biotite. The

ground-mass filling is an almost eutectic mixture of perthitic orthoclase and quartz. The quartz contains cavities similar to those described in the G granite.

The inclusions found in the G 1 granite are of three different kinds: (*a*) Little oval patches, crowded with small biotite-flakes, rarely showing haloes, in a fine granular ground-mass of felspar (mostly oligoclase), and small quartz without crystalline form, but with numerous straight rods of apatite, are seen throughout, and sphene is not uncommon. The largest of these inclusions differ only in that the biotite tends to segregate in clusters. The quartz shows lines of strain-pores, but the usual cavities are absent. (*b*) More irregularly shaped inclusions of varying size, exceeding in some cases 2 feet in length, with a ground-mass of oligoclase, quartz, and biotite, and fewer rods of apatite, but some stout prisms. In the ground-mass are spherical quartz-phenocrysts. These inclusions seem to be derived from some earlier rock. (*c*) Altered Culm inclusions: these are black in hand-specimens, and in thin section they show skeletal pale-brown biotite, giving brilliant polarization-colours, and quartz enclosing numerous spherical grains of fresh cordierite, with some dark minute inclusions, some of which appear to be spinel. The granite border is banded poikilitically through its various crystals by large cordierite-grains.

In Coombe Farm Quarry (No. 3) the junction of the G 1 granite with the Lower Aluminous Series is a very sharp one, its upper surface, where it forms a thick sill flowing south-westwards, being corrugated into the Culm. On the east side it makes a straight, clean-cut, nearly vertical contact of the dyke with the Culm; at both these surfaces the granite shows very little chill, and the orthoclase-phenocrysts go right up to the Culm.

The fine-grained granites G 2 include not only the numerous veins and sills, but also a local later intrusion of fine-grained granite on the eastern half of the length of border dealt with. This granite is, from its surrounding geological structure and from its intrinsic characteristics, undoubtedly a later marginal intrusion. It is first seen at the Sharp Tor-Forder Fault in the bottom of Fingle Glen, and also stops at another fault at Willingstone. Moreover, it is associated with a monoclinal fold of the Culm in an east-and-west direction, showing by the banded bedding of the strata northward dips of 82° at Prestonbury Camp and of 86° on Broadmoor Common, and with this sharp roll there is great flattening-out of the Culm on the south, or high side of the fold. This flattening-out of the southern edge of the Culm rocks commences as far west as the two East Underdown faults; and since, all allowances being made for the G 1 Hunter's Tor dyke and sills about Coombe Farm Quarries, there remains a large margin, it seems probable that the G 2 granite-intrusion extends underground as far as these faults: so its width would be about

$2\frac{1}{2}$ miles from the East Underdown to the Willingstone Faults. The ground east of the latter faults has not been examined, and it may extend still farther in this direction.

A small but good junction of the G 2 granite with the Culm can be seen on Uppacott Down, near the cart-track leading to Hannicombe Wood. About 4 inches from the Culm the granite changes from a fine biotite- to a tourmaline-granite, some of this mineral being of a pale cobalt-blue in thin section. This continues to about 2 inches from the Culm, where for a width of about half an inch the granite becomes finely banded with small brown tourmalines and small spherical quartz-grains in the ordinary quartz-felspar ground-mass. For the remaining $1\frac{1}{2}$ inches to the Culm, the granite becomes much coarser, some of the felspars being nearly three-eighths of an inch long of orthoclase, laminated with closely-twinned albite, while the Culm at the junction is changed into tourmaline-quartz-rock. Linscott Quarry shows the fine granite of medium grain similar to that found in Fingle Glen, and contains quartz-phenocrysts, which on fractured surfaces have more or less pyramidal ends, while the micas are sometimes as large as those of Butterdon Down. The 30-foot G 2 granite-vein in Fingle Glen is precisely the same rock as that at the bottom of the Glen; but it may be mentioned that its western side has been pneumatolysed with much yellow and bright-blue tourmaline and scarlet felspar. A section of this edge-rock shows a considerable amount of mortar-structure.

Generally, the G 2 granite contains very little apatite, or the rarer accessory minerals found in the G and G 1 granites: nor have any xenoliths, or basic patches been noticed.

Considering the three varieties of granite described above as the result of successive intrusions of the same magma, we cannot expect any hard-and-fast line to be drawn between any of them. Also, there is nothing constant in respect of flow-structure: all the granites show this more or less; or it may locally be entirely absent, and the orthoclase-phenocrysts placed in any direction. They may show parallelism for the length of the visible exposure, but they frequently resemble the swirling movements of convection rather than actual flow. A striking example of this occurs in a road-cutting west of Chagford, where the parallel flow of the G granite is sharply cut across by a 9-foot dyke of G 1 granite, with almost circular swirls of convection. This clearly shows that here the granite was solid at the time of the intrusion of the dyke.

The aplite-dyke seen at Sandy Park Millhouse Quarry is a rock of uniform grain, with felspar-crystals varying from 1·5 to 2 mm. in length. The majority of these are perthitic albite-orthoclase, while the plagioclase-crystals are oligoclase with $8\frac{1}{2}°$ extinction-angle, their refraction being the same as that of Canada balsam, and a little below that of quartz. The quartz is in slightly smaller crystals, but it occurs in aggregates of several grains differently oriented, and has many of the usual Dartmoor cavities.

The only other mineral seen is the almost opaque dark-greenish variety of tourmaline, and a crystal or two of the ordinary brown-flecked-with-blue variety. No apatite or other highly refractive mineral occurs. The rock is crystalline-granular, with small granophyric patches of the angular variety up to 6 mm. across. A very similar aplite, but of a little finer grain, and in somewhat fresher condition, was passed through in the 100-foot deep boring at Outer Down House, west of Chagford.

From what can be seen at the junctions of the granite and the Culm rocks, there does not appear to have been any noticeable absorption or solution of the latter by the granite. The contact caused, rather, a surface pneumatolytic action, producing abundant tourmaline, than a fusing or solution of the Culm rocks.

I desire, in conclusion, to record my thanks to Dr. J. S. Flett and to Dr. H. H. Thomas for determining the affinities of doubtful rocks found in the area, and to Dr. E. H. Young, of Okehampton, for assistance in the field work.

EXPLANATION OF PLATE XXIV.

Fig. 1. Tourmaline-sphene-vein in Culm hornfels; Coombe Farm Quarry (No. 4) (78 S.W.). The section shows the hornfels at the top, while in the quartz-vein are numerous pale-brown tourmaline prisms; associated with these are many spindle-shaped crystals of sphene. No. 153 *a*,[1] Dr. E. H. Young's section, × 26, ordinary light.

2. Pneumatolysed keratophyre; East Underdown Farm Well (78 S.W.). The slide shows generally a very fine biotite-alteration in the ground-mass; but, on the left, the tufted plagioclase may be seen. In the centre is a cleared area of fresh secondary albite, showing striation, and blue tourmaline-prisms. Several small perthitic phenocrysts are unaltered. No. 648, × 11, crossed nicols.

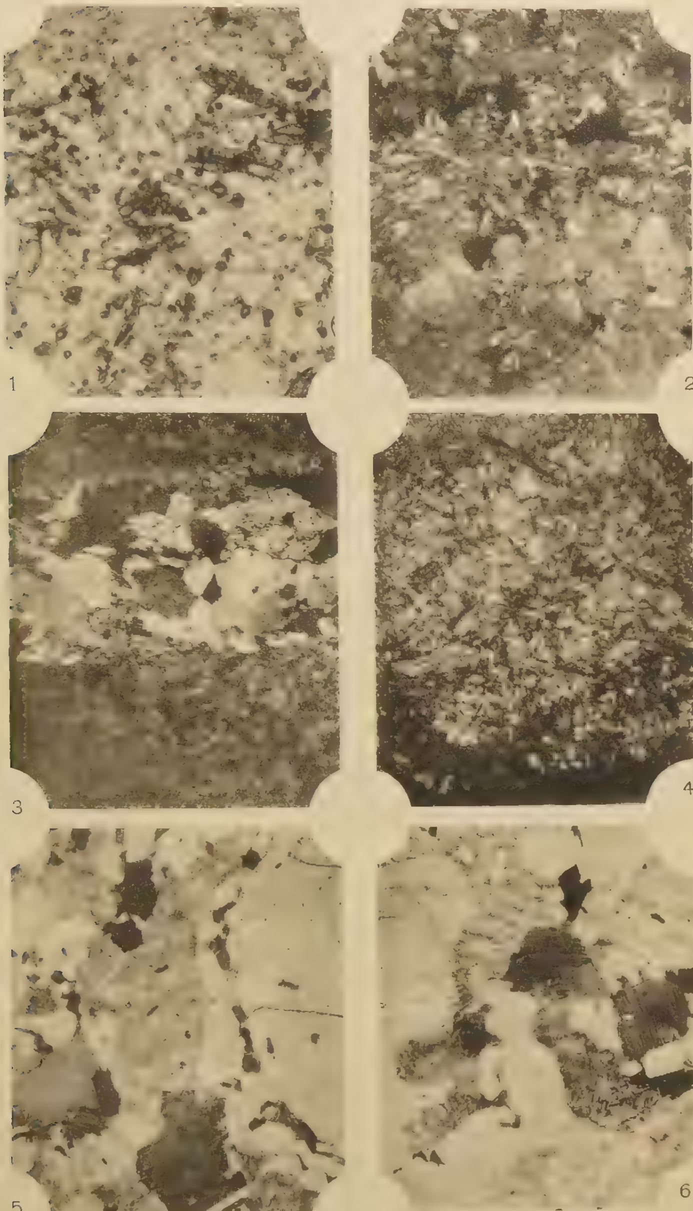
3. Scapolite-vein in porcellanite; Natton Hill Quarry (78 S.W.). The figure shows a vein of scapolite with a little pyroxene. Crossing the field, away from this, are oriented grains of pyroxene, giving a crystalline-granular appearance to the cherty ground-mass. No. 656, × 11, crossed nicols.

4. Diopside-axinite-hornblende-schist; north of Drewston House (78 S.W.). The section shows large pyroxene-crystals, with a little axinite and felspar. In this are numerous little rod-crystals of blue hornblende; these are densely packed together near the bottom at a cleavage-plane. No. 678 *a*, Dr. E. H. Young's slide, × 26, ordinary light.

5. G1 granite ground-mass; Outerdown Borehole, Chagford (89 N.E.). The figure shows part of a quartz-phenocryst, with a marginal ring of secondary biotites. The cracks in the quartz are filled with fluorite; and a large apatite-grain is seen at the left centre. No. 424, × 11, ordinary light.

6. Cordierite in G1 Granite; New Quarry, Whiddon Deer Park (90 N.W.). Below the centre, on the right, is a cordierite area showing basal lamination; to the left of this is another area in which the cordierite is altered to pinite. The biotite shows two generations; perthitic orthoclase, plagioclase, and a large apatite-grain are also seen. The quartz is full of inclusions. No. 635, × 11, ordinary light.

[1] These numerals refer to the slides in the Author's collection.



C.W.Osman photo micro

Zinco Collotype Co. Edinburgh

NORTH DARTMOOR ROCKS

Discussion.

Dr. J. S. Flett said that the Author's map seemed to prove that the north-eastern margin of the Dartmoor granite followed a fairly well-defined horizon in the Culm Series, and was passing northwards at a rather low angle beneath the sediments. In fact, the mass was behaving as a laccolite, as seemed probable also for all the Cornish and Devon granites, as to which evidence was available in this respect. No case of a 'cauldron-subsidence', or of a granite which had eaten its way upwards principally by 'overhead stoping', had yet been established in this province.

Dr. A. Brammall regarded the paper as a very valuable contribution to our knowledge of Dartmoor geology. The granite types in the area described by the Author appeared to correspond closely with those recorded by the speaker & Dr. H. F. Harwood[1] as occurring in the area to the south, around Widecombe. In both the Whiddon Down and the Widecombe areas, the composite and laccolitic character of the granite-intrusion is demonstrable. Analogy between the granite types of the two areas may be expressed thus :—

Whiddon Down Area.		Widecombe Area.
... ..	Stage 1.	Dark fine-grained granite, of comparatively basic composition.
G. Country-rock Granite	Stage 2.	Giant Granite — tor-cappings rich in killas-xenoliths, and containing garnet, cordierite, and its associates.
G 1. Second Granite—A cordierite-biotite-granite	Stage 3.	Blue granite (quarried), showing little evidence of contamination with killas.
G 2. Third Granite	Stage 4.	Minor intrusions.

The speaker's Stage 1 type is characterized by distinctive microstructure and mineral composition. It indicates appreciable differentiation from the parent magma, and came in place apparently in two ways: (1) by direct intrusion, (2) as clots caught up by large bodies of later magma more normal in composition. If this type be regarded as melanocratic, its leucocratic complementary is represented by a coarse- or fine-grained highly felspathic rock with a characteristic association of accessory minerals (sphene, pale amphibole, and native gold and silver). The speaker enquired whether the Author had observed either of these types in his area, and whether his G 1 type had been observed as intercalates in G. The Stage 3 type (Widecombe) is often intercalated as thick sills in the mass of the earlier granite; such intercalates were thus more or less immune from direct contamination with country-rock. Though much detailed work, both petrological and chemical, still remained to be done, if the granite-types in one area were to be decisively traced into another area, it was encouraging

[1] Min. Mag. vol. xx (1923) p. 53.

to note that two areas 8 to 10 miles apart showed the degree of correspondence indicated.

Mr. HARFORD J. LOWE, in a written contribution to the discussion, expressed his interest in the fact that the chiastolite occurred in an aluminous series of rocks above those characterized by pyrites. He pointed out that, although marcasite was common in the black limestone of Drewsteignton, chiastolite, so far as he was aware, had not hitherto been found in that district. It would, he suggested, appear to indicate a greater degree of metamorphism than had formerly been noticed; from which it had been inferred that the angle of slope of the granite was greater in that quarter than in most other contact-areas.

He was further interested in the sequence of three granitic intrusions characterized mainly by a decreasing size of mineral constituents, the latest (of finest grain) forming sills and a border-sheet. The implication that the subsequent intrusions had affected the original coarse-grained mass was in keeping with an explanation that he himself had put forward[1] to account for the lake-like hollow in the granite of the Chagford and Moretonhampstead area, the eastern and northern boundary of which was formed by the metamorphic rocks dealt with by the present Author.

Dr. J. W. EVANS asked what evidence there was of the Oligocene age of the crushed syncline.

The AUTHOR, in reply to Dr. Flett, remarked that he quite agreed that the Dartmoor granite-intrusion differed in many respects from the allied granites on the west, and that its strikingly different superficial shape and the comparatively low angle of dip between the granite and the Culm rocks, as also the sheet-like character of the secondary intrusion, indicated a laccolitic origin for this granite rather than a stock. The more regular oval shape of the granite-areas on the west appeared to represent domes of granite, and these were, as Dr. Flett remarked, probably independent masses, with the exception of the Land's End and Constantine areas, which seemed to have an underground connexion.

The Author was greatly interested and gratified to know that Dr. Brammall had found a corresponding series of successive intrusions of granites in the more central portion of Dartmoor, south of the area with which he had dealt, and that, in addition to the three granites of the northern border, a still earlier granite of a dark hue and more basic composition had been found. As the Author had been greatly puzzled by the occurrence of the dark holocrystalline inclusions in the G and G 1 granites and could not account for their origin, he would be glad to send specimens to Dr. Brammall and to know whether these are derived from his first granite. These inclusions usually occur in ovoid form, up to 9 or 10 inches in diameter. Evidently, this shape is due to absorption; but there occurs on the top of the cliff, on the

[1] 'The Teign Valley & its Geological Problems' Trans. Devon Assoc. vol. xxxv (1903) p. 631.

[July 25th, 1924.]

west side of Nattadon Common, a similar though much larger inclusion of oblong shape over 2 feet long, which without doubt has been derived from an earlier granite-rock.

Replying to Dr. Evans's enquiry regarding the evidence for the age of the syncline, the Author referred him to the Geological Survey memoir on Sheet 339, where this subject was dealt with.

Postscript to the Discussion.

[Referring to Mr. H. J. Lowe's letter, the Author would remark: First, in regard to chiastolite, that this mineral is only found in the Lower Aluminous Series between the hornfelses of the pyrites zone and the black slates of the top of that series: that is, it occurs at about an equal height above the granite surface where the temperature appeared to favour the formation of this particular mineral; nearer the granite the andalusite form only is occasionally found. Secondly, that the lake-like depression seen from Hunter's Tor is shown by cross-sections to be an illusion, and the wide alluvium embayments are entirely the result of fluviatile and subaërial erosion on granites of varying resistant powers and friability: while vertical erosion is limited by the River Teign's capability of cutting down the gorge of Fingle Glen.

The varying resistances of the granites are due to (*a*) the coarse G granite being a weaker rock than the G 1 granite; (*b*) to the G 1 granite's intrusion breaking up the G granite; (*c*) the G 2 granite- and pegmatite-dykes and veins further broke up the G granite and to a less extent the G 1 granite; (*d*) the crushed Oligocene syncline had a much greater effect on the already weakened G granite than on the secondary intrusions, so that we find the alluvium bays confined to the G granite. Where the Teign first met the harder G 1 granite it cut small gorges, and these have since tied the river to fixed positions: for instance, at the southern end of the Rushford Wood G 1 mass; at Highbury Hill; 600 yards above Hunter's Tor; and at Hunter's Tor itself.—*C. W. O., January 9th, 1924.*]

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13. *On a* HYBODONT SHARK (*TRISTYCHIUS*) *from the* CALCIFEROUS SANDSTONE SERIES *of* ESKDALE (DUMFRIES-SHIRE). By Sir ARTHUR SMITH WOODWARD, LL.D., F.R.S., F.G.S. (Read January 23rd, 1924.)

THE Elasmobranchs of the Carboniferous Period, already known by more than isolated teeth or spines, are very different from all the Elasmobranchs of the Mesozoic and Kainozoic Eras. Some of them approach the theoretical ancestors of the sub-class in their internal anatomy [1] and in the skeletal supports of their fins [2]; others are peculiar in the development of bilaterally symmetrical plates in the cranial roof,[3] or in the presence of dermal head-plates [4]; others seem to have a dentition intermediate between that of the Selachii and the Holocephali,[5] which have been distinct orders since Jurassic times; and a few form an unique group in which at least the symphysial teeth do not fall out when done with, but fuse with their successors and hang in front of the mouth, either forming a complete spiral [6] or falling away at occasional intervals.[7] Only one specimen has been briefly noticed [8] that seems to approach more nearly the later types of sharks, and this is now worthy of detailed study and description.

The specimen in question is the anterior portion of a small shark shown of the natural size in fig. A (p. 339), and it was referred by Traquair to *Tristychius*, probably *T. arcuatus* Agassiz. It is displayed on the counterpart halves of a slab of shale from the Calciferous Sandstone Series of Eskdale (Dumfries-shire), and is now in the Royal Scottish Museum, Edinburgh. I am indebted to Dr. James Ritchie, Keeper of the Natural History Department, for the opportunity of investigating it.

The cartilages shown in the fossil are calcified in small tesseræ, which seem to occur only in one superficial layer, not penetrating more deeply. They therefore correspond in structure with the calcified cartilages of recent sharks. The remains of the head are crushed and obscure, but the jaws are sufficiently well preserved to prove that the mouth is terminal. The teeth (fig. B) are closely

[1] B. Dean, Mem. Amer. Mus. Nat. Hist. vol. ix (1909) p. 231 (*Cladoselache*).
[2] *Id. ibid.* p. 218 (*Cladoselache*).
[3] A. S. Woodward, forthcoming paper in the Jubilee Volume of the Société Géologique de Belgique.
[4] A. S. Woodward, Q. J. G. S. vol. lxxi (1915) p. lxviii (*Oracanthus*).
[5] *Id.* Proc. Linn. Soc. Lond. Sess. 133 (1921) p. 34 (Bradyodonti).
[6] A. Karpinski, Verhandl. Kais.-Russ. Min. Gesellsch. St. Petersb. ser. 2, vol. xxxvi (1899) p. 361 (*Helicoprion*).
[7] A. S. Woodward, Q. J. G. S. vol. lxxii (1916–17) p. 1 & pl. i (*Edestus*).
[8] R. H. Traquair, Geol. Mag. 1888, p. 83 (*Tristychius*).

arranged in the usual transverse series, none being fused together into plates. Their crown is low and antero-posteriorly elongated, rounded at the ends, and usually widest and slightly elevated in the middle. The ganodentine (or 'enamel') is smooth, only marked sometimes by a median longitudinal ridge, which produces an acute median apex. The crown overhangs the root, which usually exceeds it in depth, is truncated below, and consists of vascular dentine of open texture. There are at least nine principal transverse series of teeth in the middle of each ramus of the jaw, remarkably uniform in shape, but some more strongly ridged than others. A few comparatively short teeth, with a tumid or rounded crown (fig. C), occur in the symphysial region; and there are a

Tristychius arcuatus Agassiz.

A. *Tristychius arcuatus* Agassiz; head and anterior portion of trunk, left side view, natural size.—Calciferous Sandstone; Eskdale (Dumfries-shire). [Royal Scottish Museum, Edinburgh.] *br.*= rays of branchial arch; *d.*[1] *d.*[2]=spines of anterior and posterior dorsal fins; *msp.*=mesopterygium; *mtp.*=metapterygium; *pct.*= pectoral arch; *r*=radial cartilages of pectoral fin.
B. Do.; some teeth of the principal series, × 10.
C. Do.; two anterior teeth, × 10.
D. Do.; denticle from the anterior border of the pectoral fin, × 5.
E. Do.; series of denticles from the posterior border of the pectoral fin; × 5.

few series of very small, smooth, low, and elongated teeth behind the principal series. In one tooth the sharp apex is clearly worn down into a rhombic flat surface. If the teeth were found isolated, they would be named either *Helodus* Agassiz or *Lophodus* Romanovsky.

Between the skull and the pectoral arch are seen a few horizontal bars of cartilage (*br.*), which may be regarded as some of the rays appended to the convex border of a branchial arch.

In the axial skeleton of the trunk a vacant space shows that the notochord was persistent. The neural arches are stout, and in contact at their base; but most of them are seen to become slender distally. A few arches immediately behind the head seem to incline forwards, as in *Pleuracanthus*. No separate neural spine can be distinguished. The ribs are short, and very slender, except at their expanded bases; they are longest in the middle of the abdominal region, as in *Hybodus*. The short hæmal arches in the caudal region are obscure, but evidently taper distally. Among the bituminized remains of the soft parts of the trunk, muscle-fibres are observable, and traces of the phosphatic contents of the alimentary canal overlap the ribs.

The pectoral arch (*pct.*) is somewhat displaced, but one half is well shown. This is widest at its sharp median angulation where the pectoral fin would be attached; and its ascending half is the more slender, tapering to the pointed upper end which is not segmented off. The pectoral fin of one side is well displayed, only slightly moved forwards, while that of the other side is disintegrated, some of its scattered remains being seen above the back of the head. As already remarked by Traquair, it is supported by two basal cartilages, which may be identified as mesopterygium (*msp.*) and metapterygium (*mtp.*). They are relatively large, their length being not much less than half the total length of the fin. The mesopterygium widens below by expansion backwards, so that its distal end is about twice as wide as its proximal end. It bears eight radial cartilages (*r.*), which are broad, closely apposed, and rapidly increase in length from the first to the seventh, which successively end in a pointed apex at the front border. The seventh cartilage seems to reach the extremity of the fin, and the tapering eighth cartilage is again shorter. It is not certain whether these cartilages are segmented, but they appear to be so at a few distant intervals. There are no free cartilages intercalated between their distal ends. The metapterygium is a comparatively narrow band of cartilage, not expanded distally, gently arched posteriorly, and touching the mesopterygium only at the proximal and distal ends. It seems to bear three radial cartilages, which rapidly decrease in length at the hinder border. The whole fin is therefore very long and narrow, and probably ends in a point, with little or no membrane extending beyond the cartilages. Large recurved hooklets, in a close-paired series, and all approximately equal in size, extend along its front border from the apex of its third radial cartilage to the distal end. Each hooklet (fig. D, p. 339) is laterally compressed and covered with ganodentine: it is hollow, and fixed to an ovoid base of vascular dentine of very open texture. A single series of about nine smaller denticles with a blunt rounded apex (fig. E) also occurs on the hinder border of the fin along a narrow black stain, evidently dermal, fringing the proximal part of the

radial cartilages. Some of both these forms of denticles are seen among the remains of the second pectoral fin above the head; and several scattered hooklets, probably belonging to the same fin, are shown from various points of view among the remains of cartilage at the back of the jaws.

The anterior dorsal fin (d^1) arises immediately behind the pectoral arch, and its spine is only imperfect by the flaking-away of its exposed face in the basal half. This spine, as usual in *Tristychius*, is much laterally compressed and marked on the side of its distal half by three well-spaced longitudinal ridges of ganodentine; the edge of its hinder face bears a series of small depressed denticles. It is supported at its base by a triangular cartilage, much deeper than broad, which would be inserted in its posterior cleft. Distally there are bituminized remains of the fin-membrane, but no traces of radial cartilages. The posterior dorsal fin (d^2), which is nearly as large as the anterior dorsal, is situated at the beginning of the caudal region. Its spine is also well-preserved only in the distal half, but it is clearly broader and more arched than the anterior spine. The three longitudinal ridges extending down its side from the apex are eventually supplemented behind by a fourth ridge, which tapers as it ends upwards. The posterior denticles have been broken away. The triangular basal cartilage is relatively broader than that of the anterior fin, and there are no traces either of radial cartilages or of fin-membrane. The pelvic, anal, and caudal fins are lacking in the fossil.

There are no remains of shagreen or other dermal armour.

The Eskdale specimen now described is another example of a shark, the dorsal fin-spines and the teeth of which have received two distinct generic names. *Tristychius*, however, which is the name given to the spines, is the older, and should thus be used for the fossil; and I agree with Traquair that the species represented is almost certainly the typical *T. arcuatus* Agassiz.

The teeth, as already noted, are clearly *Helodus*-like, and would have been assigned by Agassiz to that provisional genus if he had found them isolated. They are, however, arranged in at least thirteen to sixteen transverse series in each ramus of the jaw, and thus much exceed in number those in the typical *Helodus simplex* Agassiz, from the English Coal Measures, which is proved by specimens in the John Ward Collection in the British Museum (Natural History) to be a Cochliodont, with pectoral fins quite different from those now described in *Tristychius*. The new specimen, indeed, justifies H. Romanovsky, L. G. de Koninck, and J. W. Davis[1] in removing from *Helodus* the comparatively narrow and deep-rooted teeth of the Helodont type such as those now made known, and in applying to them a distinct generic name (*Lophodus*), while referring them, with *Orodus*, to a shark of the

[1] J. W. Davis, Trans. Roy. Dublin Soc. ser. 2, vol. i (1883) p. 403.

Hybodont or Cestraciont group. The dentition of *Tristychius* is essentially Hybodont, only the number of the transverse series of teeth slightly exceeds that in the typical Mesozoic Hybodonts, *Hybodus*, *Acrodus*, and *Asteracanthus*.[1] It is at least as great as the number in the jaw of the Carboniferous Edestid *Agassizodus* (or *Campodus*) *variabilis*.[2] The same form of dentition may have characterized other genera, for teeth of species of '*Lophodus*' are numerous in the Carboniferous Limestone, in which the fin-spine named *Tristychius* is replaced by other small fin-spines that must be regarded as generically distinct.

The axial skeleton of the trunk, so far as preserved, with the peculiar elongation of the ribs in the middle of the abdominal region, likewise agrees with that of the typical Mesozoic Hybodont, *Hybodus*.[3] The pectoral fin, however, although possessing two basal cartilages, as in the case of many recent sharks (including *Cestracion*), is somewhat different from the two known pectoral fins of *Hybodus*,[4] which exhibit a small propterygium articulating with the pectoral arch, and are provided with a large dermal expansion beyond the radial cartilages. In the extent of the cartilages the pectoral of *Tristychius* suggests a more primitive arrangement; but, unfortunately, it gives no clue to the mode of origin of the dibasal or tribasal fin. It makes no nearer approach to the parallel bars in the pectoral fin of the primitive *Cladoselache*; while the relatively small size of the metapterygium, with its radials, seems to negative the ordinary theory of the derivation of the modern Elasmobranch pectoral fin from a biserial 'archipterygium' like that of the Palæozoic Pleuracanths.

It must suffice, for the present, to conclude that sharks closely related to the Triassic and Jurassic *Hybodus* and to the succeeding *Cestracion*, with the dibasal mode of insertion of the pectoral fin, were already in existence at the beginning of the Carboniferous Period.

[1] A. S. Woodward, Catal. Foss. Fishes B.M. pt. i (1889) pp. 250–321.

[2] O. St. John & A. H. Worthen, Palæont. Illinois, vol. iv (1870) p. 318 & pl. viii.

[3] C. Brown, Palæontographica, vol. xlvi (1900) p. 155; E. Koken, Geol. & Paläont. Abhandl. n. s. vol. v (1907) p. 270.

[4] C. Brown, *op. cit.* p. 156; E. Koken, *op. cit.* p. 274.

14. *On a* Recently Discovered Breccia-Bed *underlying* Nechells (Birmingham), *and its* Relations *to the* Red Rocks *of the* District. By Prof. William S. Boulton, D.Sc., F.G.S. (Read January 23rd, 1924.)

[Plate XXV—Sections.]

Contents.

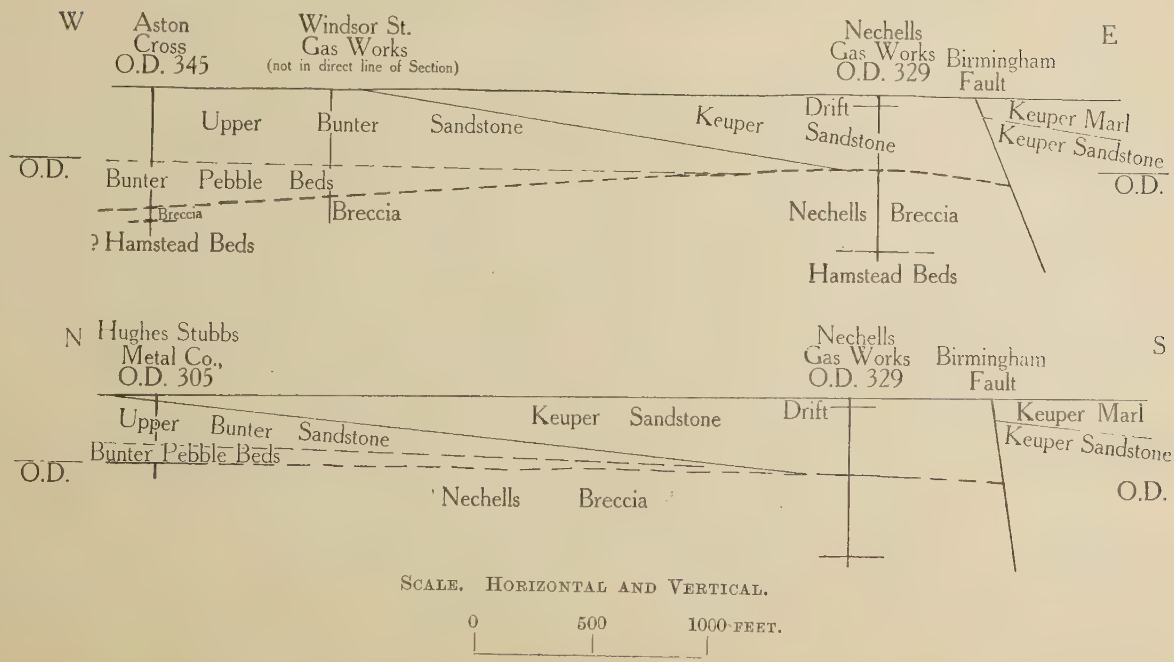
For many years it has been known that certain breccias occur immediately below the Bunter in the Birmingham district, irrespective of the well-known development in the Clent Hills and near Northfield, about 7 miles south-west of Birmingham. In 1890 C. J. Gilbert described such breccias at the base of the Bunter Pebble-Beds in Sutton Park, 7 miles north of the city, and showed that they lie with pronounced unconformity upon red clays and sandstones, and are covered unconformably by the Bunter Pebble-Beds.[1] During the last ten years, my attention has been directed from time to time to similar occurrences at the base of the Bunter met with in borings for water in and around Birmingham. In the recent re-mapping of the district by the Officers of the Geological Survey, a considerable development of these breccias has been noted, more especially at Hopwas, 2 miles west of Tamworth, and in the district round Little Aston and Streetly, a little to the north of Sutton Coldfield. Mr. G. Barrow has proposed the name Hopwas Breccia for these beds, and a description of them and their relationship to the Trias above and the Carboniferous below will be found in the recently published Lichfield Memoir.[2]

It is evident, however, that the Geological Survey is still in

[1] 'The Geology of Sutton Coldfield' (privately printed) 1890, and Geol. Mag. 1918, p. 232.

[2] 'The Geology of the Country around Lichfield' Mem. Geol. Surv. 1919, pp. 122–29.

Fig. 1.—*Sections illustrating the position and relations of the Nechells Breccia.*



doubt as to the geological age of these rocks. In the Lichfield Memoir they are classed as Permian (?), and in the accompanying 1-inch map they are bracketed with the Trias; while the relation of the Hopwas to the Clent Breccias is left an open question, although in the preface to the Memoir Sir Aubrey Strahan states that the Hamstead Beds are 'unconformably overlain by the Hopwas and Clent Breccias.'

During the past year a deep boring at the Nechells Gas-Works in Birmingham has yielded information of considerable interest, which seems to throw new light on the significance and relations of these breccias, and possibly on the 'Permian' of the Midlands generally.

I. The Nechells Boring: Description of the Cores.

This boring, put down in 1922 for a supply of water, is situated at Nechells Gas-Works, north-east of the city of Birmingham, and about 200 yards west of the Birmingham Fault, which runs north-east and south-west through the centre of Birmingham and brings down the Keuper Marls on the east against the Keuper Sandstone and Bunter Beds on the west (fig. 1, p. 344). From a consideration of the geology of the district immediately surrounding Nechells, as shown in outcrops and boring records, it was anticipated that the boring would pass through about 300 feet of Keuper Sandstone and from 450 to 500 feet of Bunter rocks. The following are the details of the boring:—

Boring at Nechells Gas-Works.

Surface-level=329 feet O.D.; diameter of boring=18 inches.

Description of strata.	*Thickness.*		*Depth.*	
	Feet	inches	Feet	inches
Made ground	1	0	1	0
Gravelly drift	54	6	55	6
Red sandstone, coarse, open-textured, and somewhat harder and browner in the lower part, with false bedding and clay-pellets	100	0	155	6
Red marl	1	6	157	0
Red sandstone, with occasional bands of shaly micaceous sandstone, and sandy shale near the base	46	0	203	0
Red and green shaly marl, mixed with sand	9	0	212	0
Red sandstone	70	0	282	0
Red sandstone, usually micaceous, with very occasional rounded and flattened pebbles; a few larger angular pebbles ($1\frac{1}{2}$ inches across) at 295 feet, and occasional chips at other horizons.	45	6	327	6
(Base of the Keuper Sandstone.)				
Red marl, with partly rounded[1] cobbles of quartzite, and a portion of a larger angular mass of quartzite (14×9 inches)	12	6	340	0

[1] As explained later, the partial rounding is probably due to the grinding action of the boring tools for many days.

Description of strata.	Thickness. Feet	inches	Depth. Feet	inches
Coarse breccia, with angular lumps of siliceous rock, some 9 inches across, and smaller chips of the same material, set in a red sandy marl-matrix	23	0	363	0
Dull-red marly sandstone	6	0	369	0
Coarse breccia, with one angular lump measuring 14×11×10 inches, being part of a larger mass of hard siliceous sandstone	6	0	375	0
Breccia, with layers of sandstone and finer breccia.	5	0	380	0
Coarse breccia, with angular fragments 9 inches across in the lower 4 feet (trilobite-fragments)	10	0	390	0
Dark-red crumbly sandstone	9	6	399	6
Marly sandstone, with angular chips up to 4 or 5 inches across	16	6	416	0
Red sandstone	2	0	418	0
Very coarse breccia, with irregular lenticles of marls, and with lumps of hard sandstone up to 11 inches across	7	0	425	0
Marly sandstone, with bands of fine and coarse breccia	5	0	430	0
Red sandstone	7	0	437	0
Sandstone, with breccia containing subangular rocks	3	0	440	0
Coarse breccia, with lumps of Cambrian limestone containing *Hyolithus*, *Coleoloides*, and brachiopods	21	0	461	0
Coarse breccia, with very angular green and grey quartzite, 6 and 8 inches across, and Cambrian rocks containing *Salterella curvata*, *Coleoloides typicalis* and *Micromitra*, in hard siliceous sandstone	5	0	466	0
Calcareous sandstone, with much hæmatite staining	4	0	470	0
Breccia, very coarse, with angular lumps and chips of red-purplish calcareous sandstone, often mottled green and red at about 437 feet, yielding *Hyolithus* and *Micromitra*	30	0	500	0
Red sandstone, with rather rounded pebbles of grey-purplish sandstone, up to 7 inches across	8	0	508	0
Coarse breccia, with angular pebbles of marly sandstone (9×8 inches) containing *Hyolithus*, trilobite-fragments, *Obolus*, *Strenuella*, *Micromitra*, *Coleoloides*, etc.	42	0	550	0
Finer breccia, harder and more sandy	16	0	566	0
Sandstone	1	0	567	0
Marly breccia	16	0	583	0
Compact breccia, with small calcareous fragments and larger siliceous chips set in calcareous sandstone (*Coleoloides typicalis*)	20	0	603	0
Coarse marly breccia, with stones up to 6 inches across, and more rounded limestone-fragments	3	0	606	0
Hard, red, non-calcareous sandstone, with bands of small angular fragments yielding *Micromitra phillipsi*	10	0	616	0
Clayey non-calcareous sandstone, with thin bands of hard sandstone	3	0	619	0
Hard sandstone, with bands of fine conglomerate, the pebbles red, yellow (calcareous), and green, with occasional large angular fragments	12	0	631	0

Description of strata.	*Thickness.* Feet	inches	*Depth.* Feet	inches
Dull-red, clayey, non-calcareous sandstone, with thin highly calcareous bands, ferruginous, weathering to a crumbly mass	3	0	634	0
Hard, pale-red, false-bedded, non-calcareous sandstone	2	0	636	0
Compact fine breccia, with occasional fragments up to 6 inches across, some of limestone. Dip about 5°	8	0	644	0
Dull-red, fine, iron-stained conglomerate, with angular and partly-rounded fragments	2	6	646	6
Hard grey sandstone	3	6	650	0
Red, sandy, calcareous marl, with no pebbles or chips, and with occasional thin beds of calcareous sandstone	17	0	667	0
Coarse breccia, with large angular lumps of calcareous sandstone up to 9 inches, and very irregularly disposed	1	6	668	6
Marl and laminated marly sandstone	1	3	669	9
Coarse breccia with blocks of calcareous sandstone	7	3	677	0
(Base of the Breccia.)				
Yellow-brown, porous, calcareous sandstone, with iron pyrites	5	0	682	0
Dense jaspery conglomerate, with red, yellow, and green rounded pebbles of fairly uniform size (¾ inch across) in a sandy matrix, which is highly calcareous, especially in the lower 4 feet. The alignment of the pebbles and fracture-planes dips at 20°	7	0	689	0
Dark-red calcareous marl, weathering rapidly	14	0	703	0
Hard, red, calcareous sandstone, the lower part variegated red and green	9	0	712	0
[Below 712 feet, the boring was stopped in dull-red marly material, from which no cores were drawn.]				

II. The General Sequence of the Beds represented in the Cores.

The sandstones, down to a depth of 327½ feet, seem to answer to the Keuper Sandstones of the Birmingham district, and no break in them can be detected. A few small rounded pebbles of quartzite and vein-quartz occur; and in the lower 150 feet scattered small angular chips of quartzite, up to 6 inches across. A 9-foot bed of mottled green and red marl comes in between 203 and 212 feet, and at 156 feet a bed of marl 18 inches thick. The thin interbedded marls of Keuper type, the highly micaceous sandstone-bands, and the frequent clay-pellety bands or isolated flattened clay-pellets, together with the dull-red colour of the sandstone, all point to Keuper rather than to Bunter rocks.

From a depth of 327½ to 340 feet no core was drawn, the boring tool churning and grinding the large siliceous blocks or cobbles in the red marly matrix for many days. It was when the boring reached this depth that my attention was first directed to it. From a depth of 327½ to 677 feet (practically 350 feet)

the rocks have a general resemblance, and may be regarded as a lithological unit. They are essentially breccias, sometimes very coarse, with remarkably angular lumps up to a foot or more across, and in some cases evidently portions of much larger boulders cut through by the boring. In other parts the breccia is much finer, and thin beds of sandstone and marl are intercalated throughout.

At 677 feet a change sets in, and no breccia is found below that depth, but the rocks are calcareous yellow-brown sandstone, dark-red highly calcareous marl, and a 7-foot conglomerate, with pebbles of red and green chert. usually about three-quarters of an inch across, set in calcareous sandstone, with much secondary calcite in places round the pebbles.

When a dip is observable, it is small (3° to 5°) in the breccia, but about 20° in the underlying Conglomerate Group.

The conglomerate (682 to 689 feet) has all the usual characters of the conglomerates of the district which occur in the Hamstead Beds (Mr. Wickham King's Middle Permian or Calcareous Conglomerate Group) extending from Brand Hall, near Quinton northwards to Great Barr Vicarage and beyond, and along the western fringe of the South Staffordshire Coalfield.

I have recently examined these conglomerates in detail, with the view of fixing the age of the beds below the breccia in the Nechells Boring.

At Hamstead Quarry (4 miles north-west of Birmingham) the pebbles are rounded, often flattened, up to 3 inches across, and occur in coarse lenticles in calcareous sandstone. In some places 60 per cent. of the pebbles consist of limestone, with Carboniferous Limestone fossils, the remainder being red and yellow chert, cherty limestone and quartzite, with occasional pebbles of rhyolite, etc. At other places calcareous pebbles are practically absent, especially in the upper part of the conglomerate of the quarry, and the red, jaspery, and yellow cherts make up practically the whole of the pebbles.

At the Hilton Shaft Sinking, 4½ miles north of Wolverhampton, now being carried out by the Holly Bank Coal Company, Hamstead Beds are being excavated (November 1922), and a conglomerate, 57 feet thick, occurs from 527½ to 584½ feet in the shaft. It is made up of well-rounded pebbles, sometimes flattened, up to 8 inches across, embedded in a calcareous sandstone base. In the upper part the pebbles are rather smaller, and consist of red and yellow chert and grey quartzite, with very few limestone-pebbles. In the lower part the pebbles are larger, and nearly 50 per cent. are calcareous, the remainder being yellow, red, grey, and black cherts, with a few of quartzite, calcareous sandstone, etc. Much of the limestone of these pebbles is fine-grained and cream-coloured, sometimes oolitic, and crinoid-fragments are common. The conglomerate is covered by red-brown sandstones

and marls with thin seams of pebbles and scattered pebbles, and is underlain by red marls.

There are no characters of the conglomerate in the Nechells Boring that cannot be matched in the conglomerates of the Hamstead Beds of the district, and the accompanying dull-red calcareous sandstones and marls are equally characteristic of this group.[1]

III. The Nechells Breccia.

The foregoing description of the cores of the boring shows that the breccia varies at different depths, being sometimes very coarse, and then the sharp angular lumps are invariably grey quartzite of Lickey type; sometimes the breccia is of the usual Clent type, with a marly matrix. In the lower part, as between 667 and 677 feet, the large lumps of calcareous sandstone up to 9 inches across are confusedly arranged, and appear to be derived from the underlying calcareous sandstones of the Hamstead Beds, to which the lumps have a close resemblance. There are also lumps of conglomerate with embedded red and yellow cherty pebbles, evidently derived from the conglomerate, or one very like it, which occurs a few feet below the base of the breccia in the boring. Occasional rounded and flattened pebbles of yellow calcareous chert of Carboniferous age occur, but of more interest are the lumps of Cambrian fossiliferous limestones.

The rocks containing Cambrian fossils occur from about 390 to 616 feet, but mainly from 450 to 550 feet in the boring. They arrested my attention at a first inspection of the cores, as being very like the red calcareous *Hyolithus* Beds in the Woodlands Quarry (Hartshill) at the summit of the Hartshill Quartzite, north of Nuneaton. They are purplish-red, or mottled red-and-green, highly calcareous, sandy rocks. Circular and elliptic sections of the whitish shells of *Hyolithus* and the slender tapering shells of *Coleoloides* were distinguishable on the surface of some of the lumps, and, when a large number of them were broken open, Cambrian brachiopods and fragments of trilobites were recognized. Mr. E. S. Cobbold has very kindly examined some of the fossils in these blocks in the breccia, and they prove the Lower Cambrian age of the material.[2]

The horizon of these fossils is just below that of the *Olenellus* Limestone at Comley in Shropshire (see Appendix, p. 369).

[1] If the conglomerate under the Nechells Breccia be regarded as roughly equivalent to the conglomerate in Hamstead New Quarry, the depth at which the Thick Coal of South Staffordshire occurs under Birmingham would be about 2600 feet. The facts and inferences embodied in the present paper, however, suggest grave doubt whether the Thick Coal Group was ever deposited in the immediate area of Birmingham.

[2] At my suggestion, a fossil collector of the Geological Survey has also searched the cores for additional fossils; these were submitted to Mr. Cobbold, and are dealt with in the Appendix.

Regarded as a whole, the lower part of the breccia consists mainly of material derived from the Hamstead Beds, the middle part of material from the Lower Cambrian Limestone and Quartzite, while the upper part is almost entirely composed of blocks of Cambrian Quartzite and highly decomposed igneous rocks, some basic, others felsitic of Uriconian type, while yet others have a general resemblance to Torridonian volcanic grits.

(1) Origin of the Nechells Breccia.

The large size and remarkably angular shapes of many of the lumps in this breccia, and the absence of rounded pebbles (except in the included lumps of pre-Breccia conglomerate) point unmistakably to the local derivation of the material. Some $4\frac{1}{2}$ miles north-west of Nechells, quartzite of Lickey type was encountered in shaft-sinking for coal at a depth of 450 yards, overlain by barren red measures; and, near by, Silurian rocks were met with at a depth of 360 yards from the surface.

The old land-surface from which the bulk of the material of the Nechells Breccia was derived is doubtless connected with this same buried ridge encountered in the colliery-workings on the north-west. But the actual source of the Breccia-material probably lay to the south-east, for which there is confirmatory evidence when we consider other breccia-deposits related to the Nechells Breccia. The rocky floor upon which that breccia rests appears to consist of Hamstead Beds, with possibly some Keele Beds, resting unconformably on Cambrian and pre-Cambrian rocks. As denudation proceeded, progressively older rocks yielded their fragments and angular blocks to the accumulation of screes: for, as we pass from the lower to the upper part of the breccia-cores, the lumps of calcareous sandstone of the Hamstead Beds give place to Cambrian limestone and quartzite, and in the upper part nearly all the material is quartzite, with subordinate fragments of decomposed igneous rocks, and volcanic grits of Uriconian type.

There is a notable absence of fossiliferous Llandovery sandstone and Silurian limestone, which are so common in the coarse breccias of Northfield and the Clent Hills, and only very occasionally do we find small round and flattened yellowish pebbles of Carboniferous crinoidal limestone, derived probably from the conglomerates of the underlying Hamstead Beds.

While the great bulk of the Breccia is in the nature of an accumulation of coarse screes deposited on dry land, there are intermittent depositions of sandstone and marl, obviously laid down in water, and it is possible that some of the finer breccia-bands were also swept down from the hill-slopes by flood-waters. The surfaces of the sandstone- and marl-bands in the Breccia are sometimes irregularly eroded, and then followed abruptly by breccia.

(2) Age and Relationship of the Breccia.

Difficulties arise when we attempt to fix the precise age of the Nechells Breccia. That it rests unconformably on the Hamstead Beds seems highly probable, because of the blocks of material in the lower part of the Breccia derived from the Hamstead Beds, and the higher dip of the Hamstead Beds below. Again, the Keuper Sandstone appears to rest unconformably upon the Breccia. The actual junction could not be seen in the cores of the boring, because, as explained above, no cores were obtained of the first 12 feet of the very coarse breccia. But, in the Birmingham district generally, the Keuper Sandstone passes down into the Bunter Sandstone, although evidence is not wanting of some overlap of the Keuper.

Thus the Breccia occupies the stratigraphical position of a large part of the Bunter Sandstone and Pebble-Beds in adjacent areas, being somewhat less in thickness than that of the Bunter rocks expected at the site of the boring, when we have regard to the known thickness of the Bunter in other borings in this district.

The Breccia cannot very well be regarded as the basal part of the Keuper, for that would involve a great depression in the Bunter rocks to a depth of some 350 feet in the Nechells area, and the filling-up of the hollow with breccia-material.

The question arises, therefore, whether the Breccia is of Bunter age (a local breccia representative of the Upper Bunter Sandstone and Pebble-Beds), or whether it is Permian: that is, of the age, as hitherto understood, of the Clent and Northfield Breccias. In the latter case the Bunter must be thought of as thinning out against a bank of breccia (fig. 1, p. 344). Up-faulting of the breccia at Nechells does not seem a likely explanation, for it would imply that the faulting occurred between Bunter and Keuper times and that subsequent to the faulting nearly 500 feet of Bunter rocks were swept off the Breccia before the Keuper Sandstone was deposited.

Perhaps the most obvious analogue is the Hopwas Breccia, originally noted and described by Gilbert below the base of the Pebble-Beds in Sutton Park, 7 miles north of Birmingham, and met with in borings for water at the base of the Pebble-Beds in and around Birmingham. In recent years it has been mapped and described by the Geological Survey in the Lichfield area.

At Hopwas, 2 miles west of Tamworth, it underlies the Pebble-Beds, and rests upon the Hamstead Beds, containing a calcareous cherty conglomerate as at Nechells. The same breccia occurs in the neighbourhood of Streetly and Four Oaks, where it attains a thickness of at least 100 feet, and consists mainly, as at Nechells, of large angular blocks of quartzite.[1]

It is known that the Hopwas Breccia is very inconstant in lateral extent and in thickness, sometimes being entirely absent.

[1] 'The Geology of the Country around Lichfield' Mem. Geol. Surv. 1919, p. 126.

In this connexion two trial-borings recently put down by the South Staffordshire Waterworks Company are of interest.

The first is at Little Hay, about a third of a mile north of the Inn and near Black Brook, and about a mile south-east of Shenstone. Here the base of the Pebble-Beds is 154 feet from the surface, the last 3 feet consisting of a hard siliceous breccia, presumably the equivalent of the Hopwas Breccia (see p. 363). From 154 to 191 feet, the base of the boring, the rocks are dark-red marls with occasional thin bands of red sandstone, and belong to the Hamstead Group.

In the second boring at Sandhills, three-quarters of a mile north-east of Shire Oak, in the Brownhills district, the base of the Pebble-Beds was reached at a depth of 393 feet from the surface, resting upon the Hamstead Beds, no Hopwas Breccia intervening.

In the City of Birmingham a breccia underlying the Pebble-Beds proper has been met with in several borings for water. Thus at Hockley Station, $2\frac{1}{4}$ miles west of Nechells, the Great Western Railway Company put down a boring in 1915–16 to a depth of 614 feet, the bottom 12 inches of which was a fine breccia in marls of Warley type.

At Aston Cross, 1100 yards west of Nechells, a boring through the Bunter Sandstone and Pebble-Beds to a depth of 658 feet probably penetrated a breccia of Hopwas type from 538 to 622 feet. I did not see this breccia myself, but the late Prof. Charles Lapworth made a note that the material was Hopwas Breccia. At John Davenport & Son's Brewery in Bath Row, Birmingham, $2\frac{1}{4}$ miles south-west of Nechells, a boring recently completed entered a breccia with subangular and angular pieces of Lickey Quartzite at a depth of 666 feet, which continued, with an intercalated band of sandstone $3\frac{1}{2}$ feet thick, to the bottom at a depth of 678 feet.

It is highly probable that the Breccia has been reached in other borings for water in and around Birmingham; but, unfortunately, the cores in many cases have not been examined by a geologist, and no reliable record has been taken. It is significant that the Nechells Breccia was recorded by the boring-foreman as 'Conglomerate with Marl', and the same description has been given by the borers for the lower parts of certain other borings where one might expect the Breccia to be encountered, as, for example, at the Windsor Street Gas-Works, about 1200 yards west-south-west of the Nechells boring and between the depth of 504 and 598 feet. At Hughes, Stubbs Metal Company's Works, 1040 yards due north of the Nechells boring, a boring carried to a depth of 350 feet probably passed through coarse breccia from about 295 feet to the bottom. Mr. Roberts, of Isler & Co., assures me that the material was coarse and angular and like the breccia at Nechells. It was described in the boring journal by the driller (the same who conducted the boring at Nechells) as 'Conglomerate with Marl', 'Conglomerate-boulders', 'Conglomerate with red stones'. This boring started in the lower part of the

Keuper Sandstone, and the upper part of the Pebble-Beds is here resting upon the Breccia. Thus the buried breccia-bank probably extends northwards from Nechells for at least three-quarters of a mile, at about the same depth from the surface, but gets much deeper westwards (fig. 1, p. 344). Taking into account the borings referred to in the vicinity of Nechells, the evidence points to a thinning-out of the Bunter Sandstone and Pebble-Beds as the Nechells breccia-bank is approached from the north-west and west, and, in consequence, the upper sandstones of the Bunter would appear to overlap the Pebble-Beds, while the Keuper Sandstone overlaps the Bunter and completely blankets the Breccia (fig. 1).

Deep borings for water in Birmingham usually stop when the Breccia is reached, so that we rarely have a chance of estimating the thickness of the Breccia and the nature of the underlying rocks. Only in the case of the Nechells boring has the Breccia been certainly passed through to its base and beyond.

It is clear that, underlying part of Birmingham, perhaps the greater part, there exists below the Pebble-Beds a coarse breccia of thickness unknown, except at Nechells, where it has been proved to be 350 feet thick. In general characters it agrees with the Hopwas Breccia of the Sutton-Streetly area. At Hopwas itself, nearly half the fragments in the breccia are well-rounded limestone-pebbles, embedded in a matrix of breccia with very angular quartzite-chips, whereas in the Nechells Breccia such rounded pebbles are almost absent. These waterworn pebbles of Carboniferous Limestone at Hopwas, as well as the few which occur in the Breccia at Nechells, were possibly derived from the disintegration of the calcareous conglomerates of the underlying Hamstead Beds, and were therefore not rounded in the Breccia period.

IV. Relation of the Hopwas Breccia to the Clent Breccia.

Again, much of the Nechells Breccia has a close resemblance to the Clent and Northfield Breccias, which are unconformably overlain by Bunter Pebble-Beds and rest upon rocks that have hitherto been classed as Middle Permian or Hamstead Beds. This raises the question—What is the relation of the Hopwas Breccia to the Clent and Northfield Breccias?

As already stated, the Geological Survey has up to the present left the matter open. Thus the Hopwas Breccia is described as of doubtful Permian age in the Lichfield Memoir, and placed as a basal bed of the Trias in the accompanying map. The Clent Breccia was classed as the Upper division (D) of the Midland Permian by Mr. W. Wickham King.[1] In the Summary of Progress of the Geological Survey for 1920, p. 14, in reference to

[1] Q. J. G. S. vol. lv (1899) p. 103.

'the red rocks succeeding the Halesowen Sandstones and unconformably overlain by the Trias,' it is stated that 'In the South Staffordshire district, as in other areas in the Midlands, it is becoming increasingly clear that the whole of these beds must be relegated to the Carboniferous System,' and, referring to the Clent Breccia (*op. cit.* p. 15): 'Up to the present the evidence is in favour of general concordance between the breccia and the beds below, while the relation between it and the overlying Trias is one of marked unconformity.'

In the Summary of Progress for 1914 (p. 23), however, the following reference is made to the last work in this district carried out by the late C. H. Cunnington:—

'It appears that the well-known Clent Breccia at the base of the Bunter is stratigraphically separable from the underlying "so-called" Permian, and is in many respects comparable to the Hopwas Breccia of the Tamworth district. In this connection it is of importance to note the occurrence in some borings at Saltley of similar breccias below the Bunter Conglomerate, which thus form a connecting-link between those of Clent, Sutton Coldfield, and Hopwas.'

Further, as already noted, Sir Aubrey Strahan, in his preface to the Lichfield Memoir, states that the Hamstead Beds are 'unconformably overlain by the Hopwas and Clent Breccias.' It would thus appear that a few years ago the officers of the Geological Survey were disposed to admit a close connexion between the Hopwas and Clent Breccias, and recognized a stratigraphical break between both these breccias and the beds upon which they rest; but that now they are inclined to group the Hopwas Breccia with the Trias, recognizing that the breccia rests upon very different horizons of the Hamstead and Keele Beds in the different localities where it occurs.

The Clent Breccia, including that in the Northfield area, they now regard as apparently conformable with the red marls and sandstones below, and the whole is brought into the Carboniferous. Thus, on this interpretation, the Clent Breccia is much older than the Hopwas Breccia, the one being Carboniferous, the other Triassic, and presumably separated by the period of great crustal disturbance which so profoundly affected the Carboniferous and older rocks before the Trias was deposited. It is clear that, if this interpretation proves to be correct and fully supported by the facts, it will mean that the assimilation of the so-called 'Permian' rocks of the Midlands to the Carboniferous, which began with the inclusion of the Keele Beds of North Staffordshire, is now complete. If the Hopwas Breccia is regarded as a basement-bed of the Trias, and the Clent Breccia is included in the Carboniferous, nothing remains in the Midlands that can be properly called 'Permian'.

The Hopwas Breccia, as already noted, rests unconformably on the beds below, as shown by Gilbert in Sutton Park, and by the Geological Survey in other parts of the Lichfield–Sutton district. If we take a wider survey, we find that similar breccias

in Leicestershire, admirably described by the late H. T. Brown,[1] rest upon Middle Coal Measures. Near Polesworth, on the north-eastern margin of the Warwickshire Coalfield, a thick calcareous breccia underlies the Pebble-Beds, and rests unconformably upon Keele Beds.[2] In North Staffordshire a calcareous breccia at the base of the Bunter lies upon a low part of the Middle Coal Measures (*loc. cit.*). The Nechells Breccia, as already explained, lies unconformably upon the Hamstead Beds.

In all these cases the breccias are unaffected by the pre-Triassic movements, and are more nearly related stratigraphically to the Trias than to the underlying rocks.

As regards their relationship to the Trias, there is abundant evidence that the breccias have been eroded in many places, previous to the deposition of the Bunter[3]; and, because of the thinning-out and disappearance of the breccias, the Trias frequently overlaps them, and rests directly upon Carboniferous or older rocks.

Again, when we consider the great thickness of these breccias in some areas (as at Nechells), their entire absence in others, their frequently coarse character, with sharp angular blocks a foot or more across, we are compelled to assume that they were derived directly from solid rocks *in situ* not far removed from the place where the breccia now rests. There is no evidence that they were derived from a previously-formed and older breccia. They should be regarded, therefore, as a breccia-formation of post-Carboniferous and pre-Triassic age, although not necessarily separated from the Trias by a great time-break.

V. The Unconformity at the Base of the Clent Breccia.

In the Clent–Lickey–Frankley area, forming the southern fringe of the South Staffordshire Coalfield, the succession from the Halesowen Sandstone upwards to the base of the Pebble-Beds has hitherto been regarded as a conformable sequence, except for the statement in regard to the breccia by C. H. Cunnington and Sir Aubrey Strahan already cited. The breccia, admirably described by Mr. W. Wickham King,[4] has a maximum thickness of about 450 feet, crops out over an area of 6 square miles, and is underlain by a series of red marls containing thin bands of *Spirorbis* Limestone, with subordinate sandstones and cornstones. Mr. Wickham King called the red marls at the base, resting on the Halesowen Beds, Lower Permian Red Marls, and they are now recognized by him and the Geological Survey as equivalent to the Keele Beds of North Staffordshire. Above them come what he

[1] 'On the Permian Rocks of the Leicester Coalfield' Q. J. G. S. vol. xlv (1889) p. 1.

[2] 'Geology of the Country around Lichfield' Mem. Geol. Surv. 1919, p. 122.

[3] *Ibid.* p. 126.

[4] Q. J. G. S. vol. lv (1899) p. 112; 'Midland Naturalist' vol. xvi (1893) pp. 25–27.

then called 'Middle Permian', having a thickness of 295 feet at Clent Hill, and subdivided as follows, in descending order[1]:—

	Thickness in feet.
Marls and one thin band of sandstone	50
Cornstone	10
Marls, and 3 to 4 feet of brown sandstone	100
Cornstone	10
Marls	100
Cornstone, and more or less calcareous red sandstone	25
Total	295

Inconstant outcrops of thin bands of bluish-grey *Spirorbis* Limestone were described by Mr. T. C. Cantrill[2] at about 50, 250, and 450 feet above the base of the Keele Beds. On the assumption that the Clent Breccia is conformable to the beds below, he contended that this discovery proved the Carboniferous age of the 'Middle Permian' (or Hamstead Beds) of Wickham King, since the highest of these bands of *Spirorbis* Limestone at Frankley is only a few feet below the base of the breccia. *Spirorbis* Limestone has been found since at other places in the district.[3]

My own work in this area has convinced me that the Clent Breccia is separated from the underlying rocks by a considerable unconformity.

In the general succession from the base of the Keele to the Breccia set out in fig. 2 (p. 357), the Hunnington Sandstone and the Romsley Sandstone, especially, with their intervening crimson marls containing one or more bands of *Spirorbis* Limestone, can be mapped over the greater part of the area from Frankley to Clent, and give a clue to the geological structure.

Reference to the sections (Pl. XXV) will show that the base of the Breccia does not maintain a constant horizon, but oversteps successive beds of the underlying series. Thus, at Merritt's Hill, the Northfield Breccia is resting on marls with *Spirorbis* Limestone, which are not far below the Romsley Sandstone[4]; at Beacon Hill, south of Rubery, the Breccia is resting on beds about 20 feet above a sandstone which is the equivalent of the Hunnington Sandstone. There appears to be a continuous upward passage, without any evidence of faulting, from the Halesowen clays at Rubery into the Keele red clay with a calcareous sandstone which corresponds in position and character to the Hunnington Calcareous

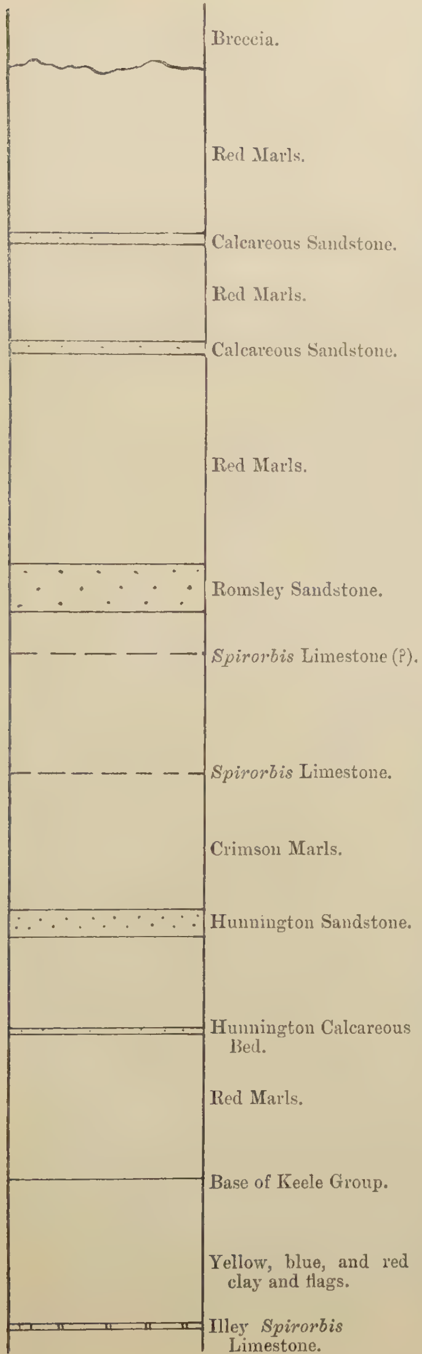
[1] Q. J. G. S. vol. lv (1899) p. 111.

[2] Geol. Mag. 1909, p. 447.

[3] 'Summary of Progress of the Geological Survey for 1920' Mem. Geol. Surv. 1921, p. 15.

[4] [Two wells recently dug (August 1924) at Merritt's Hill, one in the marls with *Spirorbis* Limestone, and the other about 65 yards to the east, dug in the Breccia, show that the junction between the marls and the Breccia is faulted at this place; for the base of the latter is at least 80 feet deep, some 50 feet from the junction. But the boundary, when followed north and south from Merritt's Hill, bends eastward, leaving this small fault, and the junction between the Breccia and the marls then becomes normal.]

Fig. 2.—*General succession of the beds in the Clent-Lickey area, on the scale of 100 feet to the inch.*



Bed, followed about 50 feet higher by a sandstone which is taken as the equivalent of the Hunnington Sandstone. At the Holy Well west of the Bromsgrove Road, it is on the marls which underlie the Hunnington Sandstone, and hereabouts is not more than about 70 feet from the base of the Keele. As we pass north-westwards, the Breccia at Waseley Hill is seen to rest on calcareous sandstones which lie above the Romsley Sandstone, and at Dayhouse Farm it overlies the Romsley Sandstone itself. The outlier of breccia at Frankley Upper Beaches rests upon the Romsley Sandstone and marls which immediately overlie it. A similar overstep is traceable as the breccia is followed farther west, past Romsley and Walton Hill to Clent Hill, where it is resting on coarse calcareous sandstones, some 250 feet above the Romsley Sandstone.

Thus, from near Rubery to Clent Hill, the base of the Breccia oversteps the underlying beds through a vertical thickness of about 500 feet, nearly the entire range of the Keele Beds as exposed in the area.

This overstep is well shown where short and steep transverse valleys cross the breccia-belt, as in Clatterbach, between Clent Hill and Walton Hill; and between Walton Hill and Romsley Hill. In these valleys, the base of the Breccia is dipping more steeply than the underlying beds; indeed, in some places, owing to gentle folding, the latter have a northward or north-eastward dip, so that the base of the Breccia oversteps on to lower horizons as it is traced southwards.

The structure of the district

as revealed by mapping the different members of the Keele Beds brings out a series of gentle folds. In the Frankley–Rubery area, the axes of the folds run east-north-east and west-south-west, while in the Clent area the dominant direction is west-north-west and east-south-east. Denudation which accompanied and followed this up-folding and faulting was sufficient in the Lickey area to remove nearly the whole of the Keele Series before the Breccia was laid down.

The main faults arrange themselves in two groups, one trending north-east and south-west, and the other nearly north and south in the Lickey area, but swinging round to a north-north-easterly direction in the Clent area. The faulting is complicated by post-Triassic movements, and some of the pre-Breccia faults were doubtless intensified by them.

Whether the Calcareous Conglomerate Group is represented in the Clent–Lickey area is uncertain. No calcareous conglomerates similar to those found farther north are exposed; but it may be that the highly calcareous coarse sandstones, with occasional very small, rounded, jaspery pebbles, which occur at the top of the succession, as at Clent Hill, are equivalent to part of the group, although they are not essentially different from some sandstones which occur lower down in the Keele Series.[1]

The breccias in the Clent–Northfield area are covered unconformably, and overlapped by, the Pebble-Beds, as in the case of the Hopwas Breccia.

It is now known that the Clent Breccia extends much farther south than the southern margin of its outcrop; for, in a boring for water at Burcot, near Bromsgrove, $2\frac{1}{2}$ miles south, which passed through the Upper Bunter Sandstone and Pebble-Beds, the breccia was struck at a depth of 633 feet and continued to a total depth of 800 feet, with a dip of about 35°. The fragments embedded in a sandy rather than a marly matrix are coarse, up to a foot across, and very angular, consisting mostly of fine and coarse felspathic volcanic ash, rhyolite, vesicular basic rock, red volcanic grits of Torridonian type, and vein-quartz, with an absence of quartzite and Llandovery rocks, which are so common in the Clent and Northfield Breccias. There are no intercalated beds of sandstone or marl.[2] Thus, coarse breccias of much the same type, resting unconformably, where their base is known, upon different horizons of the Hamstead and Keele Groups, and covered unconformably by the Bunter Pebble-Beds or Upper Bunter Sandstone

[1] Since I gave Mr. W. King an outline of my evidence for the unconformity at the base of the Clent Breccia, he has informed me that, after a thorough re-examination of the ground, he has modified the interpretation which he published in 1899; and he agrees that the Middle Permian (Calcareous Conglomerate Group) is absent, except for about 50 feet at the north-eastern end of Clent Hill, and perhaps 20 to 30 feet at the northern end of Romsley. He also agrees that the unconformity at the base of the breccia is considerable.

[2] I am indebted to Mr. Wickham King for some particulars of the Burcot Boring

(except at Nechells, where they are covered by the Keuper Sandstone), occur along a belt of country extending from Hopwas, near Tamworth on the north, to Burcot, near Bromsgrove, 25 miles away to the south-south-west. The thickness and nature of the breccia-material along this belt are as follows:—

Locality.	*Thickness in feet.*	*Nature of breccia-material.*
Hopwas.	60	Carboniferous Limestone 40 per cent., Cambrian quartzite and Silurian sandstones, and highly decomposed igneous rocks.
Streetly and Mere Green.	100	Mainly Cambrian quartzite, with sandstone, igneous rocks, and a few limestone-pebbles.
Nechells.	350	Mainly Cambrian quartzite, with Cambrian limestone, Carboniferous sandstones, igneous rocks, etc.
Northfield.	350	Cambrian quartzite and much Silurian limestone and sandstone; volcanic ash.
Clent.	450	Cambrian quartzite, Llandovery sandstone, acid and basic volcanic rocks.
Burcot.	170 +	Volcanic lavas and ashes, grits and flaggy rocks.

In the northern part of the area the breccia thins away westward and disappears, while in general it thickens and becomes coarser on the south and east. In the Hopwas area, the materials of the breccia consist mainly of the limestone-pebbles and detritus from the underlying Hamstead Beds; in the Streetly–Four Oaks area a few miles away to the south, the Cambrian quartzite of the ancient floor has contributed directly to the breccia; at Nechells, the lower part of the breccia is made up chiefly of material from the underlying Hamstead Beds, while the middle and upper portion has been derived directly from the Cambrian and, to a smaller extent, pre-Cambrian floor.

In the Northfield–Clent area, Silurian as well as Cambrian and pre-Cambrian rocks have by their denudation yielded material, while in the extreme south at Burcot, the rocks in the breccia are practically all pre-Cambrian volcanics and volcanic grits.

From the foregoing facts we seem to obtain a glimpse of an ancient ridge or hill-range of Lickey type situated east of the Birmingham Fault, and extending in a southward direction from the River Tame north-west of Tamworth, past Sutton Coldfield, Birmingham, and Northfield, and thence to the east and south of the Lickey Hills. It is not suggested that the range had an axial trend north-east and south-west, parallel to this fault. It was probably a very irregular and rugged upland, with its main fold-lines north-west and south-east, or Charnian in direction.[1]

The Permian Breccias of North Warwickshire (Polesworth)

[1] See W. Wickham King, Q. J. G. S. vol. lv (1899) p. 127.

and those fringing the Leicestershire Coalfield are probably a northward continuation of the breccia group now under consideration. Throughout the whole stretch of country, upwards of 40 miles in length from north-east to south-west, the breccia deposits are very variable in thickness, and are absent in places; but throughout they have the same general characters, being always unconformable to the rocks below and covered unconformably by the Trias above. At no place in this long stretch, where their base is actually seen, do the breccias rest upon any rocks older than the Coal Measures, despite clear indications that the pre-Carboniferous land, from which the large angular blocks in the breccia were derived, cannot be far distant from the known breccia. At any time a boring may reveal the breccia at no great depth, blanketed by the Keuper, as in the district immediately east of Birmingham, with the breccia resting directly upon Cambrian or Archæan rocks. Such an occurrence is already known at Market Bosworth, on the east side of the Warwickshire Coalfield.[1]

A student of Midland geology cannot fail to be impressed with the fact that the smooth-faced Keuper is masking a very rugged and complex floor of ancient rocks, which appears to have sunk in great blocks before and after their infilling by the Triassic sediments, and concurrently with the uplift of the visible Coal-Measure areas.

VI. The Breccias of the Quinton–Warley–Hamstead Area.

The Upper Permian marls, with occasional intercalations of fine breccias, in the southern part of South Staffordshire were described by Mr. W. Wickham King[2]; and those said to occur in the Hamstead area by Mr. W. H. Hardaker.[3] After a detailed examination of the Hamstead area dealt with in Mr. Hardaker's paper, I am unable to confirm his account of some of the rocks, or to agree with the classification that he adopts. In particular, the sub-group (70 feet thick) which he names the Manor House Permian, is really part of the same sandstone group as Hardaker's Breccia and Sandstone, and which he correlates with Wickham King's D′, or basal bed of the upper division of the Lower underlying divisions, named by him Old Quarry Sandstone sub-group and Rock Farm Conglomerate sub-group.[4] The whole succession, from the conglomerates in the Hamstead New Quarry to the unconformably overlying Bunter Pebble-Beds, is well shown in the adjacent Canal Cutting, and is set out in the section (fig. 3, p. 361). Overlying the marls with lenticular sandstones in the New Quarry, in which Hardaker found the fossil foot-

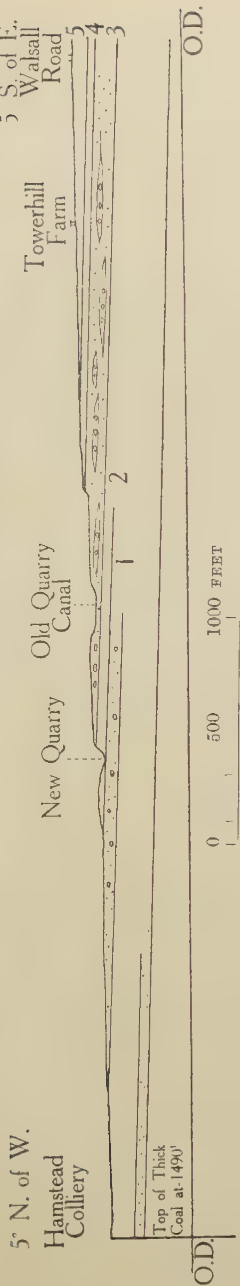
[1] Q. J. G. S. vol. xlv (1889) p. 31.

[2] *Ibid.* vol. lv (1899) p. 115.

[3] *Ibid.* vol. lxviii (1912) p. 639.

[4] This interpretation is, in part, recognized by Mr. H. Kay, 'From Coal Measures to Trias in the West Bromwich–Sandwell–Hamstead Area' Proc. Birm. Nat. Hist. & Phil. Soc. vol. xlv, pt. 4 (1921) p. 155.

Fig. 3.—*Section from Hamstead Colliery to the Walsall Road.*



Scales, horizontal and vertical.

1 = Sandstone and conglomerate. 2 = Sandstone and marl (footprints). 3 = Sandstone, with lenticles of conglomerate. 4 = Red marls. 5 = Bunter Pebble-Beds.

prints described in his paper, the sandstone-beds which succeed are about 80 feet thick, and dip at a very gentle angle (about 2°). The sandstones are dull red, false-bedded, and contain lenticular masses of conglomerate, which are well shown in the New Quarry and along the Canal Cutting. These conglomerates are in all respects similar to the calcareous conglomerates in other parts of the Hamstead Beds, but nowhere in the ground described by Hardaker is there anything that can be properly defined as breccia. All the pebbles are well rounded, with very rare exceptions, where one or two subangular fragments may be collected.

The sandstone, with its lenticles of conglomerate, is succeeded by red marl, unconformably overlain by the Bunter Pebble-Beds, the base of which, consisting of a foot or so of fine breccia, is seen at a spring on the canal-bank, 100 yards west of the Walsall road. Thus, if there are any breccias following on the Conglomerate Group (Hamstead Beds) in this area (apart from the thin breccia at the base of the Bunter), they must occur on the east buried under the Bunter.

The breccias of Warley, Perry Hill and Langley, north of Quinton, and in the Handsworth Railway-Cutting, mentioned in Mr. W. Wickham King's paper,[1] are very fine-grained, with many

[1] *Op. cit.* pp. 116–18.

of the fragments rounded, and often take on the character of breccia-sandstone, the beds as a whole consisting of red marl. These marls apparently follow on the underlying Conglomerate Group to the west, with a conformable junction. The breccias were regarded by Mr. King as the attenuated representative of the Clent and Northfield Breccias on the south. In that case, a difficulty arises, seeing that the upper marls with their contained breccias are here apparently conformable with the Calcareous Conglomerate Group, while the Clent Breccia, as we have seen, is markedly unconformable. It is possible to regard the marls and fine breccias of Warley, etc. as belonging to an older (Hamstead) group than the Clent Beds. On the other hand, according to Mr. King's interpretation, they would represent more or less continuous deposition in landlocked water-basins, while elsewhere coarse breccias were accumulating on the higher ground. It may even be that the junction of the upper marls and the Calcareous Conglomerate Group is a masked unconformity, representing a considerable time-break.

VII. Midland Breccias of Triassic Age.

In many places in the Midlands thin breccias, usually calcareous, occur at the base of the Bunter Pebble-Beds and the Keuper Sandstone, and some of them were mapped by Edward Hull and Sir Andrew Ramsay in the original survey, and are indicated on the 6-inch Horizontal Sections of the Geological Survey.

Along Pendlestone Ridge, east of and overlooking Bridgnorth, the basal 20 feet of the Bunter Pebble-Beds consists of partly angular, but mostly rounded fragments, many calcareous, and the surface of the Lower Variegated Sandstones is very irregular and much eroded at the junction. A similar basal bed occurs at Abbots Castle Hill, 2 miles east of Claverley.

At Ribbesford, about a mile south of Bewdley-on-Severn, the bottom 12 feet of the Bunter Conglomerate is a well-bedded sandstone, full of angular and subangular lumps and chips, often 6 inches and sometimes 1 foot across, of fine volcanic ash, melaphyre, quartzite, sandstone, etc., very like the fragments contained in the breccias of Stagbury Hill, a mile and a half away to the south, and Warshill, 2 miles away to the north.

At Astley, about 3 miles south-west of Stourport and at the north-eastern foot of the Abberley Hills, there are good road-sections on the north and south-west sides of the church, exposing the basal part of the Keuper Sandstones, consisting of a roughly-stratified breccia. The fragments are generally small and up to 3 inches across, usually rounded, but many angular and subangular. Rhyolitic ash is common, together with fragments of quartzite, vein-quartz, banded volcanic grit of Uriconian type, siliceous grit, Wenlock (magnesiferous) Limestone, etc.[1]

[1] Mr. W. Wickham King, with whom I examined some of the breccia-exposures in the Severn Valley, kindly helped in identifying these rocks.

In the Barr Beacon district, some 6 miles north of Birmingham, the base of the Bunter Pebble-Beds is marked by a narrow band over 2 miles long, coloured on the new 1-inch Geological Survey map of the Lichfield area as Hopwas Breccia, and noted by J. Landon many years ago.[1] It is well shown in a sandpit on the south-west side of the Beacon at the cross-roads. Here soft, red, false-bedded sandstone, of Bunter type is exposed for about a depth of 25 feet, covered by the normal Pebble-Beds. Small angular chips, mostly quartzite, are sparsely scattered through the sandstone, and more plentifully along the irregular bedding-planes. The general character and behaviour of this sandstone is much more like a basal Bunter bed than the true Hopwas Breccia, and I regard it as of Triassic age. Similarly, the 3-foot breccia at the base of the Pebble-Beds at Little Hay (see p. 352) may be a true basement-bed of the Bunter.

In the foregoing localities, the fragments in the basal breccias of the Bunter Pebble-Beds and Keuper Sandstone are mostly rounded, and many of the rocks can be matched with those of the breccia-fragments of the older Permian breccias. It is to be expected that the streams which swept along the Bunter pebbles would scour and erode the already deposited Permian breccias, more or less rounding the fragments in the process. Such derived breccia-fragments form a basement-bed, which can now be mapped as a continuous band of fairly uniform thickness for considerable distances. Further, it will not be surprising if in some cases a difficulty arises when we have to decide whether a particular deposit is a true basement-bed of the Trias made up of derived breccia-material, or whether it is of pre-Triassic age.

VIII. Classification of the Midland Pre-Triassic Red Rocks.

Since the above was written, Mr. T. H. Whitehead, of the Geological Survey, who has been remapping part of the district under consideration, has published a very useful historical summary of the 'Permian' Red Rocks of South Staffordshire and adjacent areas.[2] He adopts the name Enville Beds (Enville Series of Arber) for Mr. Wickham King's Middle and Upper Permian, or the Lower Permian of Salopian type of Edward Hull. Because of their supposed conformity among themselves, and with the underlying Keele Beds, they are placed 'provisionally with the Coal Measures'. It is admitted, however, that 'there may occur local non-sequences, as, for example, at the base of the "trappoid breccia"' (*op. cit.* p. 172).

There seems good reason, as Mr. Whitehead suggests, for

[1] 'The Barr Beacon Beds' Proc. Birm. Phil. Soc. 1890, pp. 124–25.

[2] 'The Subdivisions of the Red Rocks formerly Classed as Permian in South Staffordshire & the Neighbouring Counties: Appendix VII, Summary of Progress of the Geological Survey for 1921' Mem. Geol. Surv. 1922.

dropping the name of Hamstead Beds, except for strictly local use, seeing that the name is already adopted for a subdivision of the Oligocene; but the suggested substitution of the name Enville Beds (following Arber) involves some difficulty. The Geological Survey in their Summaries of Progress for some years have used the name Hamstead Beds for the rocks following on the Keele Beds, but without in the meantime fixing any definite upper limit thereto. In the Appendix cited above (p. 171), Mr. Whitehead says:—

'Mr. Hardaker correlated his Hamstead Quarry Series in part with the Middle Permian, and in part with the Upper Permian of Mr. King. If this correlation be accepted, it follows that the term Hamstead Beds, as used in the Lichfield Memoir, includes by implication the Middle Permian, and part, at least, of the Upper Permian of the latter author's classification.'

But, as shown on p. 361, there is no Upper Permian (Breccia Group) in the Hamstead Quarry Series of Hardaker. So that it is not merely the substitution of the name 'Enville' for 'Hamstead', as hitherto used by the Survey, which is in question; since the former name is now suggested to include both Middle Permian (Calcareous Conglomerate Group) and Upper Permian (Breccia Group). As so applied to the 'Permian' of South Staffordshire, it would tend to obscure the fact that there is an unconformity at the base of the Clent and other allied Breccias, and moreover it would leave us with no name for the Middle or Calcareous Conglomerate Group. If the unconformity at the base of the Clent Breccia and other related Breccia-Beds is admitted, it seems desirable to have distinctive names for the Middle and Upper Divisions of Hull and King. I therefore venture to urge the adoption of the following terms for the pre-Triassic Red Rocks of the Midlands:—

$$\left.\begin{array}{l}\text{3. Clent Beds}\\ \text{2. Corley Beds}\end{array}\right\} = \text{Enville Beds of the Geological Survey.}$$
1. Keele Beds.

The Keele Beds are admittedly separable on palæontological as well as on lithological grounds, and are grouped with the Carboniferous. The Corley Sandstones and Conglomerates of Warwickshire are typical of these beds throughout the Midlands, and Mr. R. D. Vernon's name for them is already adopted by the Geological Survey for Warwickshire; while in the Clent Hills we have the thickest and best-known development of the Breccia Group. In this classification the breccias of the Clent Hills and of Northfield, Nechells, Hopwas, Polesworth, and those of Leicestershire, all markedly unconformable to the rocks on which they lie, belong to the Clent Beds. Because of their discontinuity, and in the absence of palæontological evidence, it is not at present possible to assign precisely the same age to all these breccia-beds; but they all post-date considerable earth-movements and denudation affecting the Coal Measures of the Midlands, and they are all unconformably overlain by the Trias. Moreover, there is the possibility that

the marls in Warwickshire (Tile Hill Marls), which overlie the typical Corley Beds, but which for the present are grouped by the Geological Survey with them, and the marls with thin bands of fine breccia (Warley, etc.), which seem to occupy a similar position in South Staffordshire, might eventually prove to be of the age of the Clent Beds.

IX. The Age of the Clent Beds (Nechells Breccia).

The Hamstead (Corley) Beds, upon which the Clent Beds (in the sense now defined) lie unconformably, are now grouped with the Coal Measures by the Geological Survey, because of their conformability to the underlying Keele Beds, with which they are also lithologically related.

The two species of *Walchia* found in the Hamstead Beds range down into the Keele Beds of South Staffordshire and the Stephanian of the Continent, and up into the Permian of France and Germany.[1] The footprints, associated with the plant-remains, described by Mr. Hardaker,[2] although not conclusive evidence, suggest a relationship with the Rothliegende of Germany.

The possibility of the Hamstead (Corley) Beds being of Permian age, therefore, must still be reckoned with, despite the conformability at their base; although in the meantime it seems not unreasonable to group them with the Carboniferous, as was recently done by the Geological Survey. But the evidence, discussed in the present paper, for the post-Carboniferous age of the Clent Beds, with which the Nechells Breccia is grouped, seems to warrant the conclusion that these beds should remain in the Permian. They may be in part the time-equivalent of the Magnesian Limestone Series of the North-East of England.

Appendix.—*The* Cambrian Fossils *from the* Breccia-Material *in the* Cores *of the* Boring *at* Nechells Gas-Works, Birmingham (embodying the Identifications and Notes made by Edgar Sterling Cobbold, F.G.S.).

The following is a list of fossils identified by Mr. Cobbold[3]:—

Brachiopoda.

Micromitra aff. *labradorica* Billings .	N 11 A, B	[520]
	N 20 B N 23 A, B N 25 A N 26 A, B N 28 A	[450]

[1] E. A. Newell Arber, 'The Structure of the South Staffordshire Coalfield, with Special Reference to the Concealed Areas & to the Neighbouring Fields' Trans. Inst. Min. Eng. vol. lii (1916) pp. 35–70.

[2] Q. J. G. S. vol. lxviii (1912) pp. 657–81.

[3] The numerals following A.T. refer to specimens in the Geological Survey Collection; the remainder are in the Author's Collection. The numbers in brackets give the depth in feet in the boring at which the specimens were found.

Micromitra phillipsi Holl			A.T. 1122	[465]
			A.T. 1124	[616]
			A.T. 1122	[616]
			A.T. 1126 b, c	[498]
Micromitra (?)	N 10 A, N 12 A, B, N 13 B, C	[520]	A.T. 1121	[465]
	N 21 C, N 22 C, N 29	[450]		
Obolus cf. *parvulus* Cobbold	N 6 D, E, N 7 A, N 8 B, C, N 9	[520]		
Acrotreta			A.T. 1126	[616]
Pteropoda.				
Hyolithus willsi Cobbold	N 1, N 1 A	[535]		
Hyolithus (Orthotheca) compressus Cobbold	N 2, N 3	[548]		
Hyolithus alatus Cobbold (?)	N 19 A	[497]		
Hyolithus sp. cf. *biconvexus* Cobbold.	N 19 B	[497]		
Hyolithus sp. cf. *americanus* Billings	N 19 E, F	[497]		
Hyolithus sp. cf. *de geeri* Holm.	N 19 C	[497]		
Hyolithus micans Billings	N 6 E, N 10 B, N 14	[520]		
Hyolithellus (?) sinuosus (?) Cobbold			A.T. 1126 c	[498]
Coleoloides typicalis Walcott, var. *multistriata* Cobbold	N 19 D	[497]	A.T. 1122	[465]
	N 21 A, N 22 A, N 27 A	[450]	1126 A	[520]
Coleoloides sp.	N 19	[497]		
	N 21, N 22, N 27 A	[450]		
Torellella lævigata Linnarsson (?)	N 21 B, N 22 B, D	[450]		
Salterella curvata Shaler & Foerste			A.T. 1121	[465]
Trilobita.				
Strenuella (?) sp.	N 6 A, B, C, N 7 B, N 8 A	[520]		
Ostracoda (?)	N 4	[548]		

Notes on the Fossils.

Brachiopoda.

Micromitra aff. *labradorica* Billings. This form differs from the Comley specimens assigned to Billings's species in the very sharp angular line between the antero-lateral and posterior slopes of the dorsal valve. See N 28 A and its counterpart N 23 D; also N 23 A, 25 A, and N 20 B. This sharp angle is reminiscent of *Micromitra (Paterina) rhodesi* Cobbold, from Comley, but in that species it is accompanied by a considerable expansion of the lateral angles.

The surface-characters are not clearly preserved, the lines of growth being marked in N 23 D by the ragged edges of the laminæ. In the Comley form they are well-marked rounded ridges. Some indication of the same type of sculpture is seen in N 26 A. In general form the shells are in agreement with Billings's species. The dorsal valve has an elevated umbo; while the ventral, if we may judge by specimen N 26 A, is the less convex, and has the umbo more or less recurved over the posterior slope.

Probably the specimens here described represent a new species somewhat intermediate in character between *Micromitra (P.) phillipsi* Holl and *Micromitra (P.) rhodesi* from the lowest fossil horizon of Comley on the one side, and *Micromitra (P.) labradorica* from near the top of the Lower Cambrian at Comley on the other.

Micromitra (?). Many fragments (N. 10 A, N 12 A & B, N 13 B & C, N 21 C, N 22 C, N 29) occur which cannot be closely identified, but show sculpture of a character suggesting the genus. Very similar fragments occur in the lowest fossil horizon at Comley.

Obolus cf. *parvulus* Cobbold (N 6 D & E, N 7 A, N 8 B & C, N 9). These specimens are quite in agreement with the type-material from Comley, but do not show the internal characters.

[A.T. 1126. The shell is very much depressed—almost too much so for *Acrotreta*.]

Pteropoda.

Hyolithus willsi Cobbold. The specimen (N 1 & 1 A) agrees closely with the type, in the rate of taper, size and form of section; but, in the absence of the dorsal lip and all trace of exterior sculpture, the identification must be considered doubtful. The type is from the '*Hyolithus* Limestone' of Woodlands Quarry, Nuneaton district.

Hyolithus (Orthotheca) compressus Cobbold (N 2 & N 3). A minute fragment near the larger piece of shell (N 2) shows the characteristic oval section, and N 3 gives the impression of the exterior showing very fine lines of growth. The type is from the *Olenellus* Limestone of Comley Quarry; Comley Horizon Ac_2.

Hyolithus spp. Seen in section on the tool-marked surface of the specimen N 19. The probable specific names are given below:—

H. alatus Cobbold. Fairly typical section.
H. sp. cf. *biconvexus* Cobbold.
H. sp. cf. *H. (Orthotheca) de geeri* Holm.
H. sp. cf. *americanus* Billings, *æquilateralis* Cobbold, and *H.* sp. indet. N 1 of Holm, 1893.

H. alatus, *H. biconvexus*, *H. (O.) de geeri*, and *H. æquilateralis*

are found in the *Hyolithus* Limestone of Woodlands Quarry, Nuneaton district.

H. sp., N 20 A, and the counterpart N 25 D. This specimen is remarkable for the indications of the transverse section which, if not due to compression before fossilization, was trapezoidal, the dorsal face being the wider.

There are indications in this specimen of a slight thickening of the dorsal face near the lateral angles. This might conceivably be due to compression, and it would require the study of several specimens to make sure that it was an original feature.

Coleoloides (N 19 D, N 21 A, N 22 A, & N 27 A). These fragments are very like the long straight tubes assigned to this genus from the *Hyolithus* Limestone of Hartshill (Woodlands Quarry), which so rarely show the surface-markings.

Hyolithus micans Billings (N 6 E, N 10 B, & N 14). These specimens correspond very closely with the straight fragments from Comley, where, however, the species seems to range from low down in the Lower Cambrian (Horizon Ab_3) up to the lower part of the Middle Cambrian (Horizon Ba_3).

Torellella lævigata Linnarsson (?).

I feel considerable doubt as to this identification, not having seen specimens from the type-locality.

Some of the specimens under consideration appear to have an oval section; but, without specially prepared (cut and polished) examples, this point cannot be said to be established. I have failed to determine (with a half-inch hand-lens) any surface-marks or lines of growth.

Some of the curved specimens are reminiscent of *Helenia*, but against this reference is the invisibility of any spiral lines on the exterior.

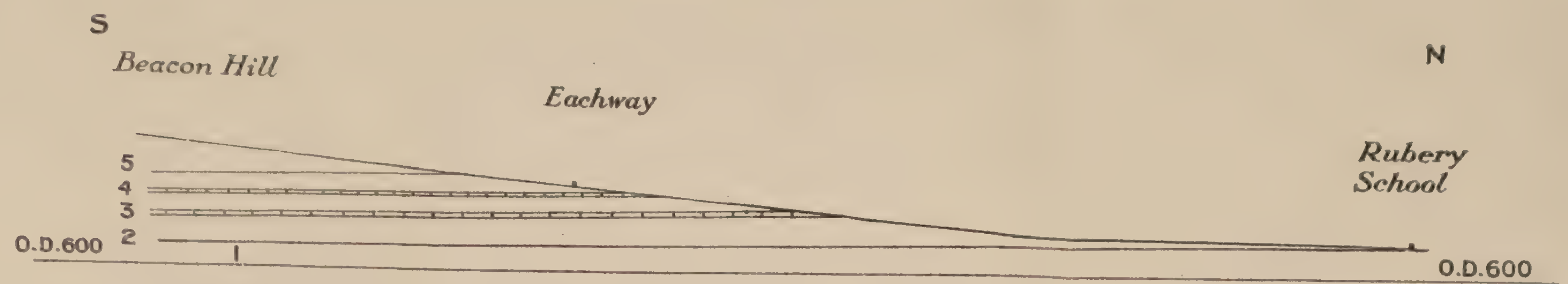
Holm tells us that Linnarsson's species is largely (say, 60 per cent.) composed of phosphate of lime. The appearance of the shells before us would suggest that such might prove to be the case with them.

Trilobita.

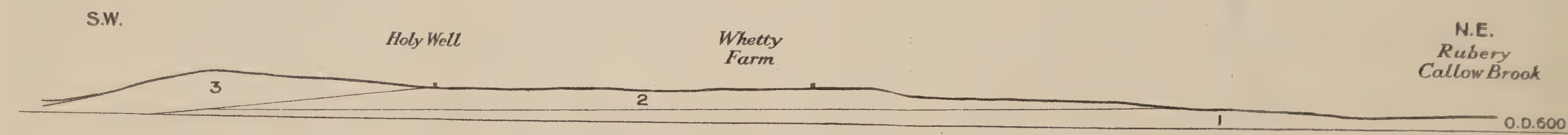
The remains of trilobites are too scanty for specific determination. So far as I can judge, they may all belong to one species (represented best in N 6 B & N 7 B), in which all the characters observable indicate the genus *Strenuella*. Other fragments are seen in N 6 A, B, & C, N 8 A.

Ostracoda (?).

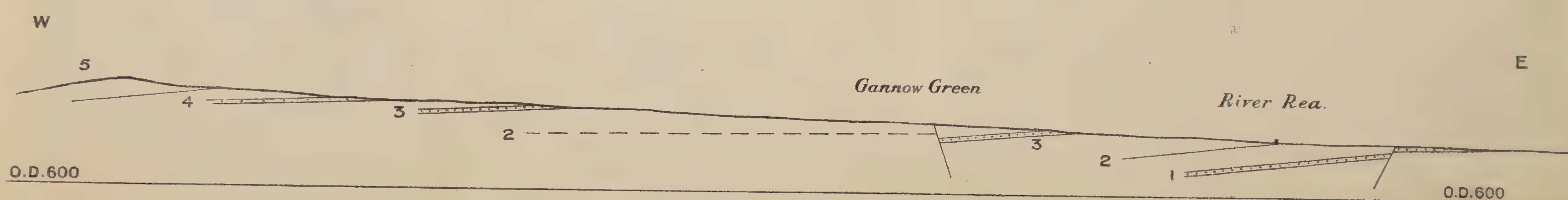
N 4 exhibits a minute body that would possibly be recognizable by someone who had studied this group of Cambrian Crustacea.



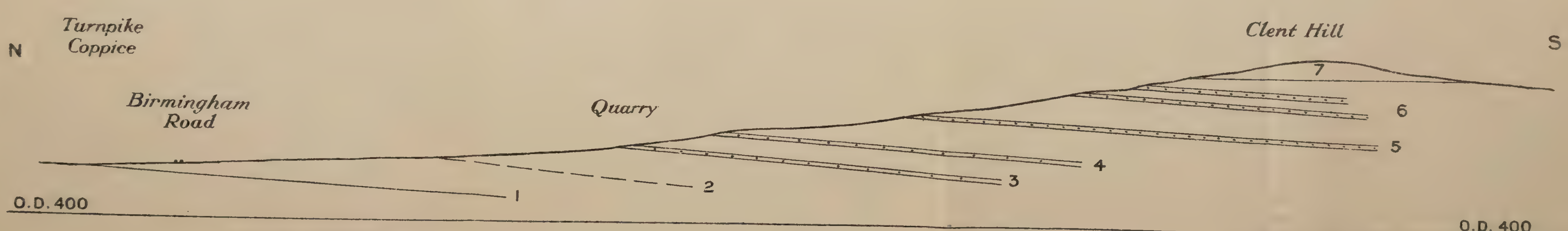
1, Halesowen Clays. 2, Base of Keele. 3, Hunnington Calcareous Bed. 4, Hunnington Sandstone. 5, Breccia.



1, Halesowen Clays. 2, Base of Keele. 3, Breccia.



1, Hunnington Sandstone. 2, *Spirorbis* Limestone. 3, Romsley Sandstone. 4, Calcareous Sandstone. 5, Breccia.



1, Illey *Spirorbis* Limestone. 2, Base of Keele. 3, Hunnington Calcareous Bed. 4, Hunnington Sandstone. 5, Romsley Sandstone.
6, Calcareous Sandstones. 7, Breccia.

[Horizontal and Vertical Scale: 12 inches = 1 mile.]

W.S.B.

Sections Illustrating the Overstep of the Clent Breccia in the Clent–Lickey Area.

Dr. G. F. Matthew describes many species which he places under six or eight genera. There are a number of bodies of similar size in my collection from the Lower Cambrian of Comley, which have not yet been worked up.

A.T. 1123. Very obscure—wants clearing from matrix. Form suggestive of *Hyolithus*; but the thickness of shell and its surface-characters (strong longitudinal costæ and ridges or folds of growth) suggest a new genus, possibly allied to *Helcionella*.

The whole of the specimens indicate quite decidedly a Lower Cambrian age for the blocks containing them, of which the breccia is partly composed, but whether more than one horizon is represented is not clear.

N 1 from a depth of 548 feet and N 19 from 497 feet may well be compared with the *Hyolithus* Limestone of the Nuneaton district, and the material of the other specimens is similar.

There is nothing like it known to occur at Comley, but the assemblage of fossils would seem to indicate a horizon rather below the *Olenellus* Limestone (Horizon Ac_2) and above the greenish-grey sandstones of the Road Quarry (Horizon Ab), which is just above the Wrekin Quartzite of that area.

EXPLANATION OF PLATE XXV.

Sections illustrating the overstep of the Clent Breccia in the Clent–Lickey area, on the scale of 12 inches to the mile, or 1 : 5280.

Discussion.

Mr. Wickham King said that he concurred with the Author's views, but definitely adhered to his opinion that the coarse Permian breccias on the south and the marls on the north are contemporaneous. The Hopwas Breccias are outside the area that he had studied in a detailed manner. He regarded Mr. Whitehead's Appendix VII to the Summary of Progress of the Geological Survey for 1921 as a splendid résumé of the alternative views, and it left room for amendments based on future discoveries. Was there below the Permian breccias an unconformity, or merely a local non-sequence? The unconformity is plain in the Abberley district, as shown by Phillips, Ramsay, Hull, and others. At Woodbury those breccias, perhaps Permian, rest on the basset edges of folded Silurian, Downtonian, and very thin Coal Measures (probably Halesowen Sandstones) divided by a thrust-plane across which the breccias lie. At Stagbury Hill those Permian breccias rest at the northern end on folded Halesowen Sandstones, and at the southern end on only 60 feet of Keele Beds. Beds 1054 feet thick at Claverley Boring had vanished before these Stagbury breccias were deposited; and pieces of the denuded Keele Sandstones and *Spirorbis* Limestones are embedded in these breccias. At Warshill

and, as shown by the Author, in the Clent-Lickey area the same unconformity exists, and in 1899 the speaker showed that part of the Corley Beds was missing at Bromley, near Kingswinford. At Enville and Baggeridge, on the north and north-west, mapping does not disclose a similar unconformity; but those Permian breccias contain Avonian pebbles, as at Nechells.

The similarity of the Corley conglomerates and the Permian breccias to those in Persia described by Blanford is extraordinary. He described conglomerates laid down under lacustrine and humid conditions, followed by thick screes accumulated under arid conditions, coarse near the hills, and fine silt in the plains. He states that this silt was probably deposited in brackish waters.

The coarse Permian breccias, when followed northwards to Gatacre and Baggeridge, do (both vertically and horizontally) become marls and sandstones, and in the higher beds gypsiferous marls do occur. In the Enville area these transitions can be followed continuously; and between Walton and Baggeridge (8 miles), and again between Northfield and Warley-Handsworth, discontinuously. The Warshill, Enville, Baggeridge, Kingswinford, Warley, Handsworth, and part of the Clent Hills Permian breccias rest upon Corley Beds and underlie the Trias. In places, as at Clent, there is a marked unconformity below the Trias. The Corley Beds apparently were deposited towards the close of the humid period, and are best associated with that period; while the Permian breccias above represent the inauguration of the arid conditions, and were laid down as coarse deposits close to the mountains, and the finer materials were carried out into the desert-plains in the manner described by Loftus and Blanford.

In the Lower Severn Valley, breccias of Triassic age, younger than those resting on the Corley Beds, often contain more abraded materials, such as would be derived from denudation, in the Triassic Period, of the earlier breccias.

In Leicestershire the Permian breccias rest unconformably on Coal Measures, and resemble those in the Abberley-Clent area, as so conclusively proved by Dr. H. T. Brown.

The Warwickshire Tile Hill Marls and Sandstones have been compared by the Geological Survey with those at Baggeridge and Gatacre. In Warwickshire no coarse Permian breccias were found, associated with these Tile Hill Beds, like those unconformably laid down over an extensive area close to the old hill-ranges, both in Leicestershire and in the Lower Severn Valley. Did not this suggest that the Tile Hill Beds are the equivalent of the Baggeridge marls and sandstones, deposited without any visible break in the plain some distance from the Mercian hill-ranges that lay on the south-east? If so, the district south-south-east of the Tile Hill Beds is one where our capitalists can be encouraged to search for the coal-supplies needed to maintain the prosperity of the Midlands.

Mr. T. H. Whitehead said that the paper raised many problems, which, owing to the lateness of the hour, could only be

discussed briefly. It seemed to the speaker that the Author was somewhat bold in correlating the Clent Breccias with the Hopwas Breccias, between which there appeared to be important differences. On the other hand, the Author was perhaps unduly cautious in hesitating to correlate the breccias of the Clent Hills with those of Warley and Kingswinford, which they resembled much more closely. The speaker agreed with Mr. King that the Clent Breccias and those of Warley and Kingswinford, and (it must be added) those of Baggeridge and Enville, could not be dissociated one from the other.

Time would not permit of defining all the points of difference between the Clent and the Hopwas Breccias; but one example might be given. Mr. King had shown that the fragments of the Clent-Enville Breccias decrease progressively in size from south to north: this did not seem to be true of the Hopwas Breccias. In the Baggeridge area, near Sedgley, the breccias were thin and comparatively fine-grained. If the breccias were eliminated altogether, a condition almost realized near Bobbington, there would result a 'Permian' succession almost exactly parallel to that in Warwickshire, where the officers of the Geological Survey had been able to detect no unconformity. The Appendix to the Summary of Progress of the Geological Survey, to which the Author and Mr. King had alluded, was prepared in consultation with the speaker's colleagues. Its object was to provide a working classification of the Red Rocks such as would eliminate the names involving the use of the word 'Permian', which had been shown to be in part definitely inapplicable and in part doubtfully applicable. It was desired to do this with no more disturbance of the grouping adopted by earlier writers, such as Hull, Lapworth, and Mr. King, than the available evidence seemed to warrant. The adoption of Newell Arber's classification appeared to attain these objects. The Author's direct evidence for an unconformity at the base of the Clent Breccia was based upon the mapping of a somewhat complicated and much obscured region. It was not possible to discuss evidence of this nature, except by a comparison of maps.

Mr. T. Eastwood remarked that, at one time, he had the impression that there was an unconformity at the base of the Clent Breccia, but detailed mapping has shown that the abnormal conditions are better explained by faulting.

The Northfield Breccia, correlated with that of Clent, differs more in pebble-content from that of Clent than does the Warley-Quinton Breccia, which the Author hesitated to classify or correlate. The Warley-Quinton area affords fairly definite evidence of a continuous sequence from the Calcareous Conglomerate Group upwards. There the marl-belt with the sandstones above the main breccia is succeeded by a fine breccia (exposed near Warley Reservoir) of similar nature to that below, indicating that the breccia part is only a peculiar phase in sedimentation of the Upper Carboniferous succession.

The speaker agreed with Mr. Whitehead's classification, in which the Clent Breccia is regarded as equivalent to the upper part of the Corley Beds of Warwickshire.

The SECRETARY read the following contribution to the Discussion, received from Mr. E. E. L. DIXON :—

'The Author has made an important step towards clearing up the long-debated question of the correlation of the "Permian" breccias of the Midlands, on which such valuable work has been done by Mr. Wickham King.

'As regards the Hopwas Breccia, the relations to the Enville Beds below and to the Bunter Pebble-Beds above are clear. In conjunction with Mr. G. Barrow, I was able to show that the breccia was completely separable from the red and yellow chert-conglomerates of the Enville Beds, and that, although in places separated from the Pebble-Beds by a plane of erosion, it was linked so closely with that formation as to allow no doubt that it was later in age than the great post-Carboniferous earth-movement. At the same time, it is remarkable that it has not only been formed under continental conditions very similar to those of the Enville Beds, but also that it has drawn on similar rocks, though in different proportions, for much of its coarse material. For instance, its pebbles of Carboniferous Limestone, which come from unknown outcrops, now possibly buried, can hardly have been derived second-hand from the Enville Conglomerates, as they are not accompanied by the red and yellow cherts of the latter.

'Consequently, Dame Nature may easily have played us a trick, and elaborated similar breccias, of which those of Warley may be an example, in Carboniferous times.

'But even if, as appears, a New Red breccia, older than the Pebble-Beds, is widespread in the Midlands, and the Carboniferous will not swallow up the whole of the old "Salopian Permian", and even if, further, we grant that this breccia is probably contemporaneous with the Permian breccias of Cumberland and elsewhere, we do not yet know whether it should be separated from the Trias as another system. The close connexion in Cumberland of the Permian breccia with the Trias—their lateral passage one into the other—, the importance of which has been pointed out by Mr. Bernard Smith, emphasizes the conclusion of Binney, Wilson, Sherlock, Hickling, and others, that the Lower Mottled Sandstone of South Lancashire and Nottinghamshire is itself of "Permian" age. These are the areas of typical fossiliferous Permian that lie nearest to the Midlands, and the classification of the Lower Mottled Sandstone of the Midlands is vitally affected thereby. The general constancy in character of the Lower Mottled Sandstone suggests that, in default of strong evidence to the contrary, it is essentially one formation throughout; but, at the same time, its close resemblance to higher Triassic strata is dead against its reference to another "system". Its relations to the Pebble-Beds are those of the Hopwas Breccia, and the fact that some exposures of Hopwas Breccia have been regarded by Landon as Lower Mottled Sandstone may be due to a lateral passage of the two formations. On this point evidence may be yielded by the heavy minerals from the various breccias, and a good start on those from the Triassic sands has already been made by Mr. W. F. Fleet.

'Direct superposition of Permian beds by Keuper implies a hiatus that would have gladdened the hearts of the old searchers for a logical line of separation between Permian and Trias, but it is exceptional, and I would ask the Author what would be the verdict of the Midland evidence as a whole on the question whether the "Permian" strata should be separated from the "Triassic" as a distinct system.'

The AUTHOR, in reply to Mr. Whitehead, admitted the possibility of the Upper Marls with fine breccias of Warley, Kingswinford, etc., being in part contemporaneous with the Clent Breccia;

but, in that case, he thought it likely that there existed a time-break at the base of the marl group.

Mr. Dixon, in his letter, opened up a wide subject which could not be adequately dealt with at that late hour. The Author regarded the Clent Beds, as defined in his paper, as more closely related to the Trias than to the Carboniferous.[1]

[1] [As against the view expressed by Mr. Dixon that the pebbles of Carboniferous Limestone in the Hopwas Breccia were probably not derived second-hand from the Enville Conglomerates, because of the supposed absence of the red and yellow cherts of the latter in the Breccia, it should be remembered that considerable masses of Enville Conglomerate in the Hamstead New Quarry, and, more especially, in the thick conglomerate of the new sinking at Hilton, north of Wolverhampton, contain pebbles which are almost entirely of Carboniferous Limestone, and, in masses of it now concealed, the contained pebbles may be all limestone. Moreover, occasional rounded pebbles of chert occur in the Nechells Breccia, very like those in the Enville Conglomerate.

Mr. Dixon's suggestion that the Hopwas Breccia may represent the Lower Mottled Sandstone of other areas has been already considered by the Author. Breccias similar to those in the Birmingham district occur underlying the Lower Mottled Sandstones in the Enville area.

As regards Landon's observations, it has been shown by the Geological Survey that much of what he took to be Lower Mottled Sandstone in the Barr Beacon District, is really part of the Pebble-Beds, but locally destitute of pebbles. The supposed Hopwas Breccia near Barr Beacon itself, which Landon thought might represent the Lower Mottled Sandstone, is regarded as the basal bed of the Pebble-Beds by the Author (see p. 363).

In his work on the Breccias of the Leicestershire Coalfield, H. T. Brown records the fact that at Packington the Breccia is overlain by Lower Keuper, as is the case at Nechells.

So long as we relegate the fossiliferous Permian of the North-East of England to a separate system, I think that we are justified in regarding the Breccias of the Midlands (Clent Beds) as belonging to the same system. But it may well be that at some future time we may see fit to unite these Upper Permian rocks with the Trias, as was formerly done.—*W. S. B., August 25th, 1924.*]

15. *The* GEOLOGY *of* SOUTHERN GUERNSEY. By DONALD JOHN FARQUHARSON, M.Sc., F.G.S. (Read December 5th, 1923.)

[PLATE XXVI—MAP.]

CONTENTS.

I. INTRODUCTION.

Guernsey, the second largest of the Channel Islands, has been described geologically in varying amount of detail by a number of previous investigators,[1] who for the most part confined their attention to the northern portion of the island, and there are only scanty references to the metamorphic complex forming the southern portion. In 1884 the Rev. Edwin Hill & Prof. T. G. Bonney (6) announced the result of their first visit to the island, and gave a few general notes relating to the southern gneisses which they believed to be, as a whole, comparable with the Laurentian Gneisses of Canada. No attempt was made to distinguish between the various types of gneiss which are now known to occur in that area.

In a paper on Alderney Canon Hill (7) discussed the age of the Channel Island rocks and, incidentally, announced his conclusion that the 'Guernsey Gneiss' is mostly—perhaps all—of igneous origin, but subsequently crushed. The conclusions of the two writers above mentioned may be summarily stated as follows:—In all the islands there are plutonic rocks—diorites and hornblende-granites—which are posterior to the gneisses and other dynamically altered rocks, but are believed to be pre-Cambrian, since in Jersey these rocks are overlain by the Rozel Conglomerate (basal Cambrian) and in Alderney are succeeded unconformably by grits correlated with the Conglomerat pourpré (Ordovician).

[1] The works included in the Bibliography on p. 387, to which reference is made in the text, are indicated by numbers in parentheses.

The main object of the present paper is to give a description of the distribution, field relations, and petrographic characters of the different types which together make up the metamorphic series, as also a brief account of the remaining rocks which come within the area under consideration. The geological succession in Guernsey may be tabulated in order of age as follows:—

D. (?) Palæozoic minor intrusions	Dykes and veins of dolerite, lamprophyre, quartz, etc.
C. Later Pre-Cambrian intrusions	Dykes (basic and acid). Granite (of Cobo). Differentiation suite.
B Pre-Cambrian sediments	Pleinmont Shale and Grit.
A. Pre-Cambrian metamorphic series	Diorite-gneiss 'β' and 'γ.' Older minor intrusions (dykes) Granite-gneiss. Diorite-gneiss 'α.' Jerbourg Schists.

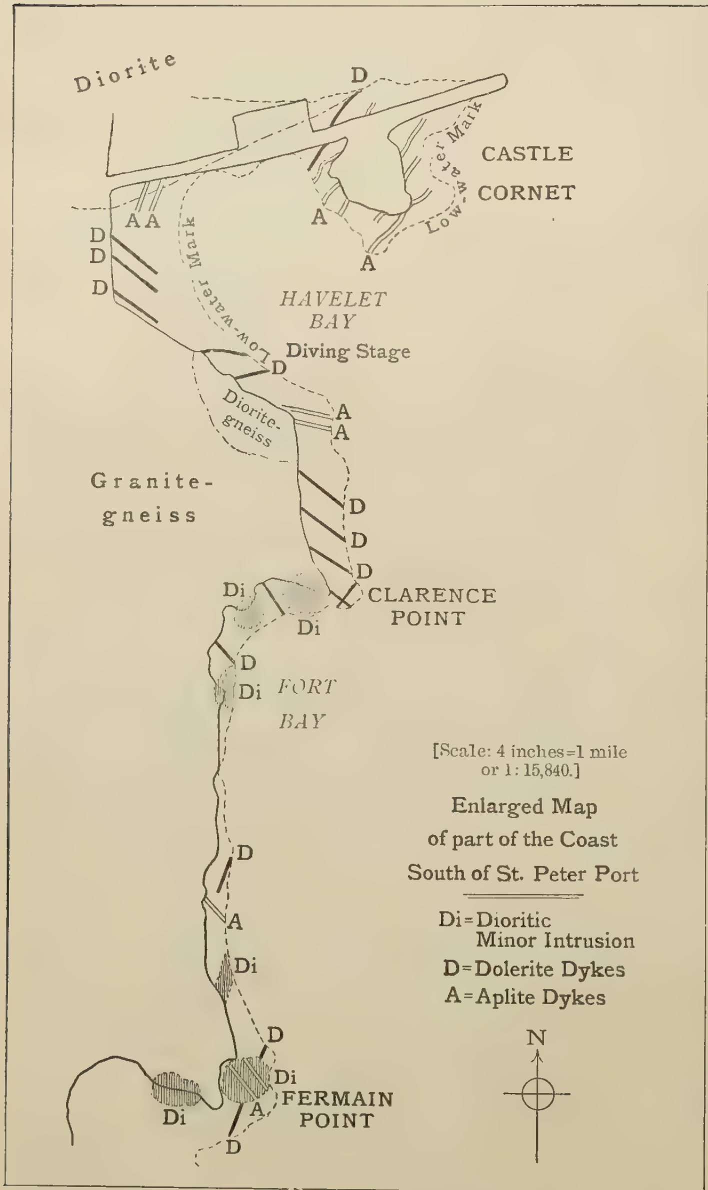
It will therefore be seen that, with the exception of some dykes of doubtful Palæozoic age, the whole of the island consists of pre-Cambrian rocks; gneisses and schists in the south, unfossiliferous shales and grits at Pleinmont, and a series of intrusions in the north, which range from hornblende-gabbro through diorites and tonalites to granites. The larger intrusions are accompanied by dykes which pierce not only the plutonic suite, but also the gneisses and grits of the south.

II. The Metamorphic Series.

The metamorphic gneisses and schists occupy an area of approximately 14 square miles of the southern half of the island. They form a high tableland terminating in cliffs some 200 feet high along the southern coast. and reaching a maximum altitude of 300 feet about a mile inland, thence sloping gently north and north-west towards Câtel and Vazon. Beautiful exposures occur in the cliffs; but, inland, where the ground is cultivated, it is only in an occasional road-cutting, an old and disused quarry, or in a heap of material from some newly-sunk artesian well that the underlying rock is visible.

The rocks of the whole of this area (excepting those which are described later) are rudely foliated, with a general strike ranging from north-west to north-east and a dip of 60° to 90° in a westerly direction. Changes in strike take place at planes of dislocation, and these abrupt changes are reflected in the physiography of the southern coast-line, as, for example, Moulin Huet, Saint's, and other bays. At Moulin Huet the strike of the gneiss on the extreme west of the bay is north-north-eastward (dip 70° north-north-westwards); but at the foot of the path descending into the bay there is a sudden change of strike at a dislocation-plane dipping 50° north-eastwards. Along this plane a 'diabase'-dyke has been intruded, which (when traced seawards) swells into a flat-

Fig. 1.



Diorite
D
CASTLE
CORNET
Low water Mark
A A
D
D
D
A
A
Low water Mark
HAVELET
BAY
Diving Stage
D
Diorite-gneiss
A
A
Granite-gneiss
D
D
D
Di
CLARENCE
POINT
Di
D
Di
FORT
BAY
[Scale: 4 inches=1 mile
or 1: 15,840.]
Enlarged Map
of part of the Coast
South of St. Peter Port
Di=Dioritic
Minor Intrusion
D=Dolerite Dykes
A=Aplite Dykes
D
A
Di
D
Di
FERMAIN
POINT
Di
A
D
N

Fig. 2.—*Sketch-plans, showing the rapid change in the strike of the gneiss-foliation produced by planes of dislocation.*

[*a.* Moulin Huet Bay ; *b.* Saint's Bay.]
Approximate scale : 16 inches=1 mile, or 1 : 3960. The plans are oriented north and south.

topped mass of basic material occupying an area of many square yards in the bay. Immediately east of the dyke the foliation strikes north 5° to 15° west (dip 80° west-south-westwards), but gradually bears round to the normal north-north-easterly direction, which is maintained as far as the eastern angle of the bay (see fig. 2, p. 377). The rocks in the neighbourhood of these dislocation-planes are apparently less resistant to marine erosion, and the bays have accordingly been developed in them.

(i) The Jerbourg Schists.

These are fine-grained schists which cross the Jerbourg Peninsula in a north-north-westerly direction as a narrow strip, about 300 yards broad. They are faulted on the south against coarse granite-gneiss, and on the north against similar granite-gneiss and diorite-gneiss of Divette type. At Divette the junction with the diorite is obscured by a broad dolerite-dyke which follows the fault.

The schists are penetrated 'lit-par-lit' by a fine-grained, pink, aplitic rock and by white quartz, forming an intricate pattern of grey schists and paler veins. The effect is greatly accentuated by weathering, for the schistose bands weather away, and the pale pink and white veins, varying in width from a fraction of an inch to a foot, project above the general surface of the rock. The intrusive rock is probably related to the Pea-Stacks Gneiss, which is described below. The strike of the schists is between north-east and east-north-east, and is therefore not quite parallel to that of the adjoining gneiss. The dip varies from 55° to 80° in a north-westerly direction, but the foliation-planes are locally contorted in such a way as to give to these rocks the appearance of highly folded sediments. A sedimentary origin may be tentatively ascribed to the schists, for the following reasons:—their mineral constitution; the rapid variation in the size of the grains, and in the relative abundance of the quartzose constituent.

Petrography of the Jerbourg Schists.—The schists are fine-grained, grey-green, chloritic, and micaceous; they are schistose in places, massive and quartzose in others. Under the microscope they are seen to consist essentially of felspar (40–50 per cent.), quartz (30–40 per cent.), chlorite and biotite (10–20 per cent.). The quartz and felspar have an average diameter of 0·3 mm., and the biotite and chlorite occur as small elongated laths enveloping the two first-named minerals, giving to the rock its sheen and dark-green colour respectively. The quartz is angular, containing many inclusions, and showing undulose extinction; the felspars show strain-shadows, and are turbid owing to the great development of sericite. Twinning is therefore difficult to detect, but lamellar twins are faintly discernible in some crystals. It is probable that both orthoclase and plagioclase were originally present, but the rock appears to have been almost entirely reconstructed.

(ii) The Gneisses.

The task of differentiating the many various types of gneiss is by no means easy. These rocks, originally described by Hill & Bonney (6) as in part altered sediments, were later (7) regarded by the former as metamorphosed porphyritic granites and diorites —the granites being composed essentially of quartz, felspar, and mica in widely varying proportions.

The gneisses vary in colour, mode of weathering, and structure, one type merging so gradually into the other that the boundaries are only occasionally well defined. Marine erosion produces smoothly rounded surfaces in some types and rugged in others. The main mass consists of coarsely porphyritic, rudely foliated, light-reddish gneiss of granitic type; the dioritic gneisses are usually finer-grained and dark green. Among the latter, three types can be distinguished: the Divette and Torteval types are clearly younger than the granitic gneiss; but there is reason to believe that the Fort Bay type is a modification of that rock, or may even be an earlier intrusion. It is convenient to describe the dioritic gneisses together, despite this difference in their age. The granitic and dioritic gneisses were separated in time by a phase of minor intrusions represented by dolerites and aplites.

(*a*) The Granitic Gneisses.

The granitic gneisses occupy the major portion of the area under consideration. They consist mainly of pale reddish, porphyritic rocks, but a pale-grey and white streaky variety occurs in Petit Port Bay, and a fine-grained micrograniitic type forms the northern arm of Fermain Bay. Another type of gneiss that is separable from the main mass occurs at the south-western corner of the Jerbourg peninsula, west of St. Martin's Point, and forms the cliffs adjoining the beautiful stacks known as the Pea Stacks ('Le Tas de Pois d'Amont').

Petrography of the granitic gneisses.—With the exception of the Pea-Stacks Gneiss, the granitic types possess many characteristics in common. The quartz, which forms 20 to 50 per cent. of the rock, is granular, shows undulose extinction, and has many inclusions (the majority of which are irregular in shape, rather resembling Chinese characters when viewed under the microscope).

The abundant felspar is to a great extent microcline, perthite, and microperthite; there is, also, some plagioclase and a little orthoclase. The felspar is everywhere in larger crystals than is the quartz, the two constituents being distinctly granular in texture. The orthoclase is mostly untwinned, but sometimes exhibits Carlsbad twins. The microcline shows blurred and indistinct cross-hatching due to mechanical disturbance; it has frequent inclusions of quartz, and micrographic quartz-felspar intergrowths

are not rare. Some beautiful granophyric pseudospherulites of microcline and quartz also occur. The extinction-angles of the plagioclase in symmetrical sections average 7°, and the refractive index is very near that of Canada balsam, thus probably indicating oligoclase. The lamellæ show signs of strain, and all this felspar is shadowy between crossed nicols.

Biotite is usually an important mineral; in some slides muscovite occurs with it, and in others totally replaces it. The biotite is brownish-green, and occurs in the form of matted aggregates or interstitial laths between the quartz and the felspar; it is generally in part altered to chlorite. Where not much chloritized it shows strong pleochroism in pale straw-yellow to purple-brown tints. Apatite is the predominant accessory, and occasionally sphene occurs, but hornblende is absent.

Wherever the porphyritic structure is developed, it is due to the increased size of the felspar-crystals which reach a maximum length of 3 inches; the quartz never exceeds half an inch in diameter, and the biotite always occurs in small plates. All these granitic gneisses betray a tendency to granulitic texture, and the medium- and fine-grained varieties are typical granulites.

(*b*) The Pea-Stacks Gneiss.

This gneiss, which occupies the limited area already mentioned, is a medium-grained rock composed mainly of quartz and pink felspar. The texture as revealed by the microscope is granulitic, and its mineral composition is roughly estimated to be :—

	Per cent.
Quartz	40
Felspar	50 to 60
Muscovite	5 to 10

The felspar is mainly oligoclase-andesine, the lamellæ showing much effect of strain; untwinned orthoclase, which has suffered alteration, forms a quarter to a third of the total felspar, but there is a notable absence of microcline. Muscovite occurs as thin scales between the quartz- and the felspar-aggregates. A dull-red mineral, occurring in small clusters or masses of conchoidal grains, or as thin plates, feebly pleochroic in blood-red to dark amber-brown tints and with a high refractive index, may probably be identified as allanite. A similar mineral has been detected in a streaked aplitic dyke cutting—and possibly incorporating (10) gneiss at Castle Cornet.

The field-relations of this rock to the Jerbourg Schists afford evidence of the greater age of the latter, since the pale-pink aplitic rock which is described on a previous page as intimately veining and permeating the schists 'lit-par-lit' bears much resemblance to the Pea-Stacks Gneiss, being composed of quartz 40 to 50 per cent., felspar 50 to 60 per cent., and muscovite about 5 per cent.

It is finer in grain than the gneiss, but resembles it in being granulitic and in containing no microcline; the felspar is mainly oligoclase-andesine, with a small proportion of untwinned altered orthoclase, but there is less muscovite. The veins are, therefore, regarded as offshoots from the Pea-Stacks Gneiss, which on its north-eastern boundary is intrusive into the schists.

It is not certain whether these schists which formed the roof of the intrusion were originally sediments or fine-grained igneous rocks, but their microscopic characters are in favour of the former view. The intrusive rock was clearly a granite, and both it and the roof-rock were at a later period affected by earth-movements which converted the one into gneiss and the other into schists.

(c) The Dioritic Gneisses.

These fall into three main types:—(α) the Fort Bay type; (β) the Divette type; and (γ) the Torteval type.

(α) The Fort Bay Gneiss only occurs within a limited area in the bay beneath Fort George; it is not easy to define the boundary between it and the surrounding granitic gneiss. The dioritic gneiss may possibly be a more basic modification of the associated rock.

The remaining types possess many characteristics in common, and it is in some cases impossible to separate them in the field, although they can be distinguished in thin slides under the microscope.

(β) The Divette Gneiss occurs typically at Divette, near the diving-stage in Havelet Bay, and at l'Erée. It is a greenish-grey dioritic gneiss, medium-grained in texture, and composed essentially of felspar and hornblende. The development of the foliation is variable; where it is prominent it is indicated by the parallelism of the hornblende-prisms, which attain a length of a quarter of an inch. In some parts of l'Erée Bay and in Divette Bay the rock is almost devoid of foliation, and resembles a medium-grained diorite.

(γ) The third type of dioritic gneiss, first noted by Canon Hill (6) in a quarry near St. Andrew's Brickfield, occupies a large area west of a line joining Vazon Bay, on the north-western coast, to the Torteval cliffs on the southern coast. A rock is also visible at low spring-tides in St. Peter Port harbour, which, although it resembles the diorites of the north, is shown by its composition and texture to be of the Torteval type.

Petrography of the Dioritic Gneisses.

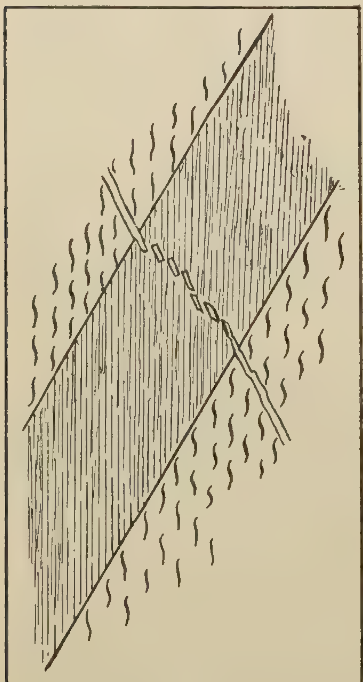
(α) Fort Bay Gneiss.—This is a dark, rudely foliated gneiss, which contains as its dominant mineral a much-corroded, hypidiomorphic hornblende, enclosing ophitically small crystals of plagioclase and quartz. The felspar is much decomposed; it is

mostly oligoclase-andesine, with some untwinned orthoclase. No microcline occurs, and quartz is present only in small amounts. Some biotite, aggregated, as in the granitic gneisses, into small clusters, and many irregular grains of iron-oxide scattered through the rock form the remaining components.

(β) Divette Gneiss.—This is a medium-grained mottled diorite, green or grey in the hand-specimen, and consisting of subidiomorphic hornblende and felspar, with some quartz, biotite, and iron-oxide. The hornblende is green, and shows moderately strong pleochroism. The felspar, despite its decomposition and its 'ultra-microscopic' twinning, can be recognized as oligoclase-andesine; the other components are interstitial quartz, a fair amount of biotite in aggregated flakes, and a few specks of iron-oxide.

(γ) Torteval Gneiss.—The rocks included in this division are dark-green dioritic 'augen'-gneisses, consisting of elliptical 'eyes' of light-greenish felspar and quartz enwrapped by hornblende and biotite. The quartz forms 10 to 30 per cent. of the rock, and the felspar is entirely an acid andesine; the hypidiomorphic hornblende is green, moderately pleochroic, and the majority of the crystals are twinned. Biotite is present in small aggregates as before: there is no iron-oxide. The rock is more akin to a tonalite than to a true diorite.

Fig. 3.—*Petit Port Bay: fractured aplite-vein crossing cleaved dolerite-dyke in gneiss.*



[Scale: 1 inch = 3 feet.]

Numerous lenticular patches of finer-grained and more hornblendic rock are characteristic of this group; they range in size up to 3 feet in length and 1 foot in width. These patches contain no quartz, their hornblende is granular, and there is much less biotite in them than in the main mass. They doubtless represent segregations from the same magma as the normal gneiss.

(iii) Older Minor Intrusions.

On the west side of Petit Port Bay, at Saint's Bay, and

elsewhere along the southern coast occur acid and basic dykes which have undergone metamorphism by the same agencies as those that produced the gneissic foliation in the porphyritic granites and diorites already described. The basic dykes exhibit greyish-green weathering, and were originally fine-grained dolerites; but they are now much altered. They do not quite conform, either in dip or in strike, with the general foliation-planes of the gneiss, but cut across the strike at an angle of about 10° to 15°. A strong cleavage has been set up in them, parallel to the strike of the gneiss, which at Petit Port is north 30° east.

At this place the gneiss and these dykes are penetrated by a vein of pink aplite 3 to 6 inches wide; but it is clear from its course across the dyke (see fig. 3, p. 382) that it has suffered from the same earth-movements as those that produced the cleavage of the dyke.

(iv) General Relations of the Metamorphic Series.

In the south of Guernsey we find a number of rock-types which have undergone considerable changes. The earliest of all, the schists of Jerbourg, constituted at some period the cover or roof of the acid intrusion (the Pea-Stacks type) which veined the overlying rocks in an intricate fashion. This intrusion was originally one of several plutonic masses which together form the Granitic Gneisses.

The intrusion of these masses and of the Fort Bay Diorite-Gneiss was separated in time from the later intrusions of the Divette and Torteval types by the phase of minor intrusions described above. These minor intrusions have suffered metamorphism along with the older gneisses, but nowhere penetrate the younger dioritic gneisses. The latter are never so crushed as the earlier types, and the 'augen'-structure of the Torteval Gneiss appears to have been produced by pressure operating shortly after intrusion. The rock is in places hardly foliated, and yet at no great distance away the 'augen'-structure is fully developed. The finer-grained lenticles of more basic material which it includes are not shattered; they appear to have been segregated at an early stage and to have existed, while deformation was in progress, in a somewhat plastic state in the more acid mother-rock which wraps around them.

Although these lenticles in the Torteval Gneiss resemble fine-grained rocks that occur in pockets and veins in the later diorites of the north (which, like the gneiss, are later than the granitic gneiss), the distinction of the two dioritic rocks is proved by their microscopic characters. The Torteval Gneiss, unlike the diorites, contains no pyrites, magnetite, or orthoclase; the biotite is never idiomorphic, and the hornblende shows no evidence of having been formed at the expense of augite, which is considered by Bonney (10) to have been the case in the other rock.

The Divette and Torteval Gneisses, although generally quite distinct, are in places hardly separable. They seem to be closely

allied, and may even be different modifications of one and the same rock, since at l'Erée Bay and south of Rocquaine Bay, where the Torteval type is well developed, there are places where the 'augen'-structure is little marked, or may even be totally absent.

At the boundary of the diorite-gneiss with the porphyritic granite-gneiss at l'Erée and along the Rocquaine coast to the south, there is an area of rock—indicated on the map as 'l'Erée Gneiss'—which contains large pink felspar-crystals, up to 2 inches in length, similar to those of the granitic gneiss, but included in a dioritic ground-mass. This suggests a mixture of the two types.

III. The Pleinmont Shale and Grit.

At the south-western extremity of the island the cliffs, for a distance of over half a mile near Pleinmont, are formed of a dark, grey-green, compact rock greatly resembling a diabase: so much so that it was described as such by Hill & Bonney in 1884 (6); but, after further examination in 1911 (10), they correctly identified it as a grit, regarding it as posterior in age to the gneiss, and comparable in many respects with the Brioverian Grit from Bec-au-Fry (Britanny). At its northern extremity in Pezerie Bay the grit is pierced by a hornblendic dyke and by three acid dykes, which also pierce the gneiss. They resemble dykes which cut the later plutonic rocks of the north of the island, where their field-relations prove them to have been intruded at no great interval after these rocks. Hence we may infer that the Pleinmont Grit is intermediate in age between the gneisses of the south of the island and the younger dioritic suite of the north, and that it was deposited after the cessation of the main pre-Cambrian earth-movements.

In 1922 Dr. G. H. Plymen (12) gave a brief description of a road-section which he discovered at Westend Cottage, about half a mile east of the Pleinmont Grit. The exposure is limited, but a pale grey-green shale in a very weathered condition is visible. More recently I came across a recent well-sinking where the Rue des Portelettes (6-inch Ordnance Survey Map, 1889) branches off towards the Imperial Hotel. This exposure is 300 yards east of Westend Cottage, and here the shale was encountered in a fresh condition immediately below the soil.

In the hand-specimen it is a fine-grained, laminated, pale grey-green shale; it is fairly soft, slightly friable, and has a soapy feel. It contains some visible pyrites, and appears to be highly chloritic. Under the microscope it is seen to be composed of small irregular quartz-grains (showing undulose extinction) and felspar (orthoclase and albite). Both are interwoven with chlorite, and speckled with pyrites and magnetite; the last-named mineral occurs as small grains similar in size to the quartz and felspar, and in larger angular masses. The chlorite is clearly secondary after biotite, which is still in part preserved as flaky sheaf-like aggregates.

Another exposure of this shale occurs in a shallow cutting on the east side of the Rue des Vilains, the northern continuation of the Rue des Portelettes. At this spot the shale, in an extremely weathered condition, is seen to rest on a floor of diorite-gneiss, on which it must originally have been deposited. The exposure is only a few yards long and not much more than 2 feet deep; but clear evidence exists of the priority in age of the diorite.

At Westend Cottage the shales are considered by Dr. Plymen to 'cease eastward by intrusion of a gneissic rock, which may be tentatively described as of dioritic origin' (12). The shale would, therefore, appear to be older than the dioritic gneiss, a conclusion which is clearly not consistent with the relations observed in the Rue des Vilains. In neither case is there any sign of baking in the shale at the contact with the igneous rock, nor is the diorite chilled or even finer-grained than the normal, hence it may be inferred that the shales were deposited on an uneven floor of gneiss, so uneven that in places (as at Westend Cottage), the appearance of igneous intrusion may be suggested, whereas deposition around an irregularity in this floor of gneiss would seem to be the correct interpretation.

Dr. Plymen regards these shales as equivalent to the Jersey formation, which is correlated with the Phyllades de St. Lô of Normandy (Brioverian). Thus it seems that the shale and grit of Pleinmont both form part of the Brioverian. Their preservation in Guernsey is probably due to faulting.

IV. Later Pre-Cambrian Intrusions.

Dr. Bonney and Dr. John Parkinson have at various dates published full descriptions of these rocks, so that little further reference to them is necessary. They appear to represent a differentiation-suite ranging from hornblende-gabbro and diorite to tonalite and hornblende-granite, and, apart from the Cobo granite, occupy the whole of the island north of the gneisses.

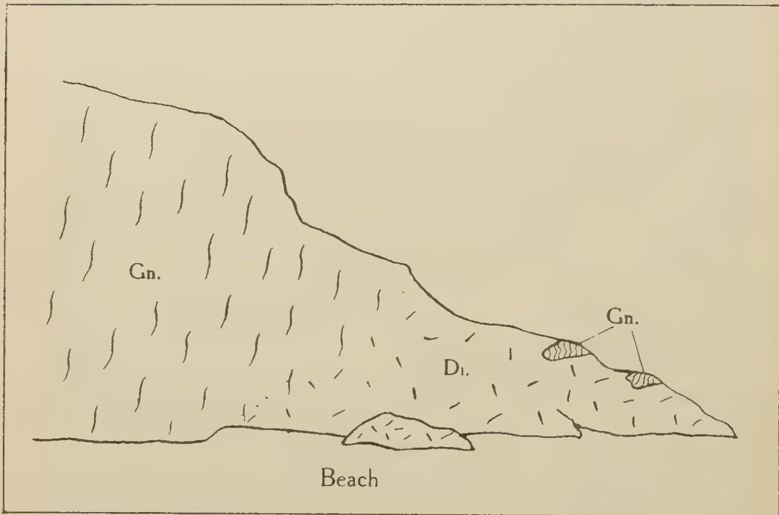
A group of small intrusions in the form of sills and broad dykes which occur in places in the Granite-Gneiss are, however, undoubtedly related to the diorites of the north. The first of these is encountered on the south side of the point on which Clarence Battery stands (see fig. 1, p. 376), and appears to persist southwards across Fort Bay. This mass consists of a cream-coloured rock contrasting sharply with the surrounding gneiss, and studded with long, idiomorphic, dark-green hornblende crystals ranging in length from a quarter of an inch to 1 inch. The rock at its junction with the gneiss is generally chilled; the hornblendes are much smaller, and the whole rock finer in grain for a width of 6 feet at the margin. Large xenoliths of gneiss, up to 6 or 8 feet in diameter, were detached by the intrusion and rotated so that the directions of foliation of any two never coincide (see fig. 4, p. 386).

The next intrusions of this type occur north of Fermain Point, where two very wide dykes dipping west-north-westwards at 60°

traverse the gneiss; on each side of the point two sills of a similar rock are seen: these rocks are of finer grain than at Clarence Battery. Owing to their ready weathering, the sills form a flat ledge on the northern promontory of Fermain Bay. When this side of the bay is looked at from the south the 'sill habit' of the intrusion becomes very obvious.

The rock from these two localities shows in hand-specimens elongated acicular prisms of dark hornblende, set in a matrix of pale flesh-coloured felspar, in which little or no quartz is visible to the naked eye; specks of magnetite are scattered throughout the rock. Under the microscope some quartz is visible as small

Fig. 4.—*Fort Bay: sill-like intrusion of diorite in granite-gneiss; view looking north-eastwards.*



[Di=Diorite; Gn=granite-gneiss.]
Scale: 80 inches=1 mile, or 1 : 792.

interstitial grains; the felspar is greatly altered, but andesine and some untwinned orthoclase are recognizable. The hornblende, which forms approximately 30 per cent. of the rock, occurred originally in beautifully idiomorphic crystals, but these are now somewhat corroded. It is commonly twinned, and is a bright-green, highly pleochroic variety. Magnetite, pyrites, some apatite, and a little sphene are the remaining constituents. A rock from the south-east of Jersey which somewhat resembles this was described by Dr. Parkinson (8), and attributed to the mixing of a dioritic with a highly felspathic magma.

North of Fermain Point three parallel dykes of red microgranite striking north 20° west, and a diabase-dyke striking north 15° east, pierce one of the sills. These dykes are exactly similar to those which in the north of the island are found to penetrate the diorites. In that region the dykes are in turn cut by compact felsite-dykes which are presumed to be pre-Cambrian, since they are of the same composition as the acid lava-flows of Eastern Jersey, which are below the Grès pourpré, or basal Cambrian grit, of Britanny (10); and pebbles of a similar rock are plentiful at the base of the Grès feldspathique (Upper Cambrian) in Alderney and at Omonville. This group of intrusions in Guernsey may, therefore, be referred with some probability to the Pre-Cambrian Era.

The intrusion of hornblende-picrite at Bon Repos Bay and many of the dyke-rocks which are so abundant on the coast-sections along the southern cliffs have been described by Bonney & Hill (10). Since they have not been mapped previously, I have inserted them on the appended map (Pl. XXVI).

One intrusion, which had not been noted before, forms the face of a small disused quarry on the Rue du Tertre, Câtel. In the field it is a purple, rusty-weathering, compact rock with columnar jointing. Under the microscope it proves to be a beautiful spherulitic felsite. The spherulites are set in a ground-mass consisting partly of lath-shaped oligoclase-andesine, and partly of a cryptocrystalline mixture of quartz and felspar; occasional laths of brown biotite measuring as much as 4 mm. in length also occur—these are easily detected in the hand-specimen. This is apparently the only locality where this rock occurs in Guernsey; unfortunately, its relations to the older rocks of the district can nowhere be observed, the surrounding area being under cultivation.

My best thanks are due to Prof. O. T. Jones for his very helpful criticism and advice.

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See also various notes in the 'Geological Section' of the Transactions of the Société Guernesiaise (formerly the Guernsey Society of Natural Science & Local Research).

EXPLANATION OF PLATE XXVI.

Geological map of Southern Guernsey, on the scale of 1 inch to the mile, or 1 : 63,360.

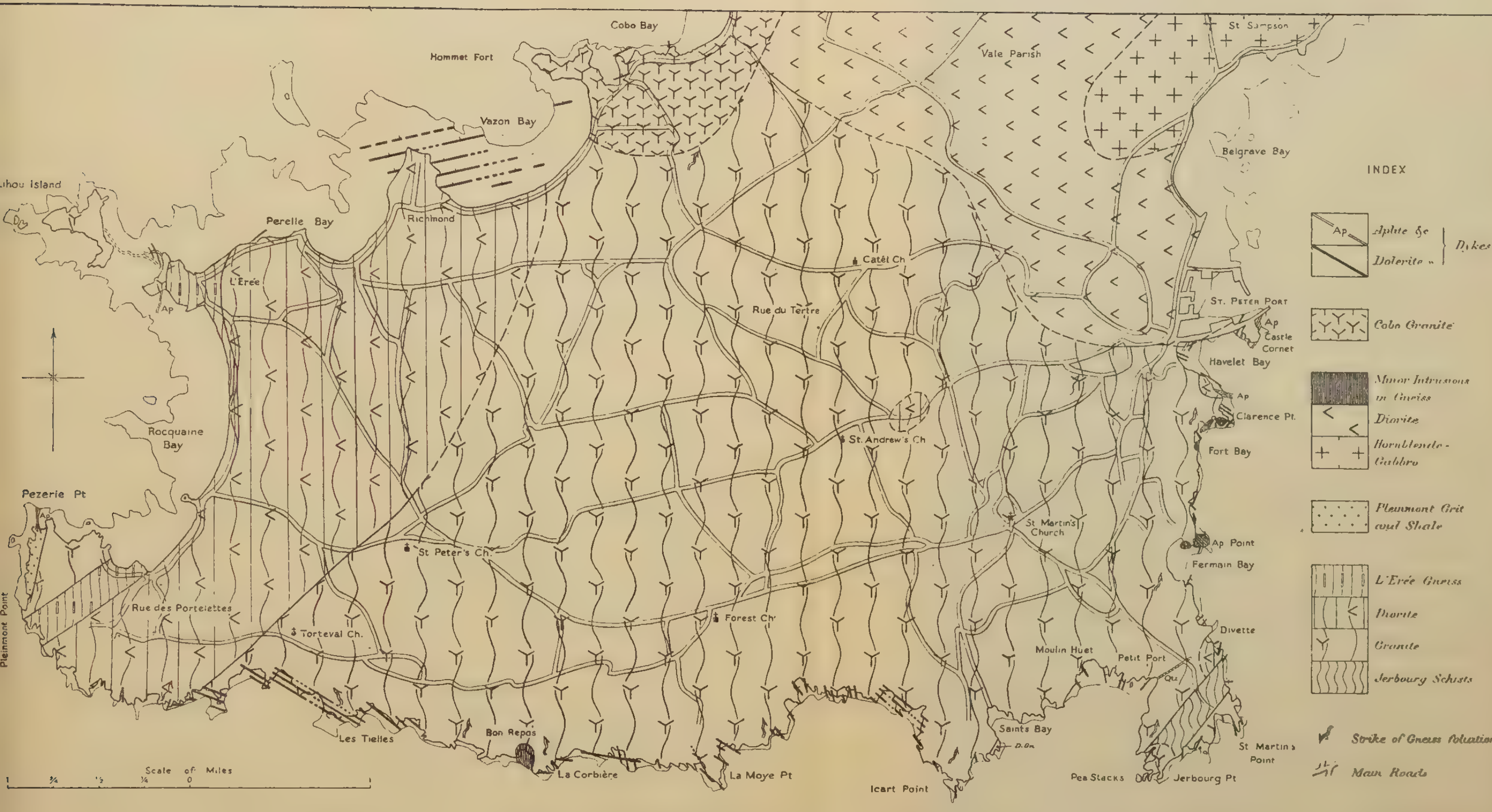
Discussion.

Dr. G. H. Plymen congratulated the Author on the interesting and useful additions which he had made to our knowledge of the geology of Guernsey. The speaker was prepared to accept the Author's view that the Pleinmont Shale was later than, and resting on, the dioritic gneiss. The apparent evidence to the contrary, at Westend Cottage, being obscured by the weathering, was inconclusive.

The noting of the Jerbourg Schist was a valuable discovery by the Author; it was probably an exposure of the Sark mica-schist of sedimentary origin, best seen at Havre Gosselin on the western coast of Sark. This mica-schist is invaded in lit-par-lit fashion by the acid differentiate of the Sark diorite-gneiss, and in Guernsey there was probably a similar phenomenon, as the Author considered that a relation existed between the granite-gneiss of the east of Guernsey and the diorite-gneiss of the west.

A notable illustration of the great length of time required for the development of the Pre-Cambrian suite of rocks was afforded by the apparent absence of gneissic material in the basement Cambrian conglomerate of Jersey; and the equally remarkable apparent absence, in the supposed early Cambrian grits of Alderney, of any representative of the very fully developed Jersey Shale.

The Author regretted that he was not better acquainted with the mica-schists of Sark, but considered that their correlation with the Jerbourg Schists would lead to the establishment of a more general succession among the metamorphic rocks of the Channel Islands.



GEOLOGICAL MAP OF SOUTHERN GUERNSEY.

16. UPPER VISÉAN CORALS *of the* GENUS *CANINIA*. By HERBERT PRICE LEWIS, B.A., F.G.S. (Read March 26th, 1924.)

[PLATES XXVII–XXX.]

INTRODUCTION.

THE present research forms part of the investigation that is being made into the structure, affinities, and distribution of the Upper Viséan Caninoid corals. The majority of the specimens were examined at the Department of Geology, University of Sheffield. I express my great indebtedness to Prof. W. G. Fearnsides for the facilities for research which have been provided and for the interest that he has shown in my work. For much help in photography, and in a great many other ways, I cordially thank my colleague Mr. W. H. Wilcockson. Mr. W. J. Rees has also assisted me in photographic work.

Prof. S. H. Reynolds very kindly conducted me over the Avon section, and for other help in the field I tender my thanks to Prof. E. J. Garwood, Miss E. Goodyear, Dr. E. Neaverson, Mr. W. H. Wilcockson, and to my brother, Mr. C. C. Lewis, who has on several occasions assisted me to collect material in North Wales.

The bulk of the material examined was the result of my own collecting. For material which has proved of much assistance I am indebted to Miss I. Balmforth, Prof. P. G. H. Boswell, Prof. W. G. Fearnsides, Prof. E. J. Garwood, Miss E. Goodyear, Dr. F. L. Kitchin and the Director of H.M. Geological Survey, Dr. W. D. Lang, Dr. E. Neaverson, Prof. S. H. Reynolds, Principal T. F. Sibly, Dr. Stanley Smith, Dr. F. S. Wallis, Mr. W. H. Wilcockson, Mr. H. Woods and the Sedgwick Museum, Sir Arthur Smith Woodward and the British Museum (Natural History).

Prof. Reynolds kindly allowed me to examine the late Dr. A. Vaughan's coral specimens and sections in the Department of Geology of the University of Bristol; and I am indebted to Dr. H. Bolton and Dr. F. S. Wallis for allowing me to examine corals in the Natural History Museum, Bristol. Sir Arthur Smith Woodward very kindly gave me every facility to examine corals in the late Mr. G. H. Morton's collection from the Carboniferous Limestone of North Wales, and other corals preserved in the British Museum (Natural History).

For help and advice I thank most cordially Dr. F. L. Kitchin, Dr. W. D. Lang, Principal F. Sibly, Mr. Henry Woods, Mr. W. H. Wilcockson, and especially Dr. Stanley Smith, who has placed at my disposal the results of his own work on *Caninia*; he has also supervised my work, and provided me with advice, literature, and material.

Finally, my thanks are due to the Council of the Geological Society for conferring on me a Daniel-Pidgeon award to aid me in the prosecution of this work.

Caninia H. Michelin.

Caninia; H. Michelin, 1840.[1] Congrès de Turin.
Campophyllum (partim); Thomson, 1893, pp. 705–20.
Campophyllum (partim); Vaughan, 1906, p. 139.
Non *Campophyllum*; Edwards & Haime, 1850, p. lxviii.
[Genotype: *Cyathophyllum flexuosum*; Goldfuss, 1827, p. 57 & pl. xvii, fig. 3, Devonian, Eifel. (See, however, C. Schlüter, 1889.)]

Genotype: *Caninia cornucopiæ* H. Michelin, 1840, *op. cit.* (See R. G. Carruthers, 1908, Geol. Mag. p. 158.) Tournaisian, France and Belgium.

Diagnosis.—Simple Carboniferous Rugose Corals, the plain (non-carinate) septa of which are longer than those of *Amplexus*, yet do not meet, or, if some fuse at their distal ends, do not form a closed fossula, as in *Zaphrentis*. There is no columella nor central column. Dissepiments are typically few, but in advanced species are numerous, forming a wide ring.

Remarks.—The species here described exhibit characters typical of the genus *Caninia*, as defined by the careful revision of that genus by Mr. R. G. Carruthers (1908) and Dr. A. Salée (1910). The species *Caninia juddi* (Thomson) is, therefore, removed from the later-established genus *Campophyllum* in which it was placed by James Thomson.

Caninia cornucopiæ Michelin, emend. Carruthers: this species resembles closely the earlier stages observed in *C. juddi* (Thomson). In the earlier development of the dissepimental zone, the latter, however, agrees with *C. cornucopiæ* var. *vesicularis* Salée (1910, pp. 24–27) and *C. cornucopiæ* mut. D_{2-3}, Vaughan (1911, pp. 555–56). The *C. cylindrica* group[2] [including *C. cylindrica* Scouler. Salée; *C. herculina* Salée (1910); *C. hastièrensis* Salée and *C. dorlodoti* Salée (1912)] differs from *C. juddi* Thomson chiefly by the discontinuity of the major septa across the dissepimental zone, the greater number of septa possessed at the adult stage, and by the more open spacing of the tabulæ.

[1] Authors' names followed by dates refer to the Bibliography at the end of this paper (p. 403).

[2] The Director of the Bristol Natural History Museum has kindly allowed me to cut a specimen preserved in that museum and possessing a polished surface, which appears to be that figured by Milne-Edwards & Haime as *Campophyllum murchisoni* E. & H. in pl. xxxvi, fig. 3, of their 'British Fossil Corals' Palæont Soc. Monogr. 1851. These authors mention that their species was preserved in the Bristol Museum (*op. cit.* p. 184). There are to be seen in horizontal section 65 major septa, a well-marked fossular break at certain stages, dissepiments, either of rectangular or of curved shape, according to the continuity or not of the septa across the outer zone; while vertical sections show the tabulæ to be greatly depressed at the cardinal fossula. All the features are thoroughly Caninoid, and appear to indicate that the species belongs to the same group as *C. cylindrica* Scouler, Salée.

Caninia patula Michelin, Salée (1910, p. 39) and *C. densa* Salée (1910, p. 48) exhibit a development markedly Palæosmiliad, and this, together with the absence of any marked Amplexoid stage, distinguishes these species from *C. juddi*.

C. samsonensis Salée (1912, p. 58 & pl. D, fig. 1), though in some respects resembling *C. juddi*, differs from it, however, in the projection of thickened minor septa for some distance from the thecal wall into the inner zone at an adult stage, and in the possession of a greater number of major septa.

Caninia juddi (Thomson).

Campophyllum juddi Thomson, 1893,[1] pp. 711–12 & pl. xvii, fig. 3.
Campophyllum cylindricum Scouler; Thomson, 1893, pp. 705–706 & pl. xvi, figs. 1 *a*–1 *f*.
Campophyllum breviseptum Thomson, 1893, pp. 708–709 & pl. xvi, figs. 4–5.
Campophyllum subfurcillatum Thomson, 1893, pp. 711–12 & pl. xvii, fig. 3.
Campophyllum heteroseptum Thomson, 1893, p. 714 & pl. xvii, fig. 7.
Campophyllum furcillatum Thomson, 1893, p. 754, explanation to pl. xvii, fig. 8.
Campophyllum furcatum Thomson, 1893, pp. 714–15 & pl. xvii, fig. 8.
Campophyllum rectangulare Thomson, 1893, pp. 715–16 & pl. xviii, figs. 1, 1 *a*.
Campophyllum amplexicum Thomson, 1893, pp. 717–18 & pl. xviii, fig. 4.
Campophyllum supraphyllum Thomson, 1893, pp. 718–20 & pl. xviii, figs. 8–8 *a*.
Caninia kokscarowi Stückenberg, 1895, pp. 197–98 & pl. iii, fig. 12, pl. xii, figs. 1 *a*, 1 *b*, 4 *a*–4 *c*.
Caninia gebauri Stückenberg, 1895, p. 195 & pl. ix, figs. 2 *a*–2 *b*.
Caninia ruprechti Stückenberg, 1895, p. 200 & pl. xvi, figs. 9 *a*–9 *b*, pl. xvii, figs. 5 *a*–5 *b*.
Caninia lahuseni Stückenberg, 1904, pp. 88–89 & pl. v, figs. 5 *a*–5 *d*.
Campophyllum derbiense Vaughan, 1906, p. 139. British Museum Nos. R. 15307 & R. 15403–404.

(No. R. 15307 is figured in Pl. XXVII, fig. 2, and is a transverse section cut somewhat obliquely, so that tabular intersections cross the central area and the extrathecal zone appears wider on the counter side).[2]

Type-specimen.—That figured by Thomson, 1893, pl. xvii, fig. 3, Upper Viséan, Harelaw (Haddingtonshire). I have been informed by Mr. Peter Macnair that Thomson's types were destroyed by fire at the Kilmarnock Museum, and that therefore no reference can be made to them.

Neotype.—That figured in Pl. XXVII, figs. 3 *a* & 3 *b*, from the

[1] In this paper Thomson describes and figures a section of one coral from Ireland as *Campophyllum (Caninia) giganteum* Michelin, pp. 709–10 & pl. xvii, fig. 1. The same section is figured in his previous paper (1883, pp. 378–79 & pl. vii, fig. 4). In that (1883) paper also, he described and gave a figured section of another coral (p. 377 & pl. vii, fig. 2) which he named *C. cylindricum* Scouler. Later, in his 1893 paper, the same figured section appears (pl. xvi, fig. 6) under the name *C. cylindricum* var. *denticulatum*, in the explanation of the plates (p. 753); but, in his brief description of the coral (p. 710), he adds that it agrees in all essential details with his *C. giganteum* Michelin. Owing chiefly to their greater number of septa and the nature of the dissepiments, neither *C. giganteum* Michelin (Thomson) nor *C. denticulatum* Thomson appears to be synonymous with *Caninia juddi* Thomson, as here defined, and in this they differ from *Campophyllum cylindricum* Scouler (Thomson, 1893).

[2] Through the kindness of the former keeper of Geology, Sir Arthur Smith Woodward, I have examined the section (R. 15307) and have been supplied with a photograph of it (see Pl. XXVII, fig. 2).

Upper *Dibunophyllum* Zone (D_2) of the Carboniferous Limestone at Wedber Brow, near Malham (Yorkshire). Preserved in the Sedgwick Museum, Cambridge.

External Characters.

Corallum.—Simple, slightly curved and conical near the proximal end, but usually becoming almost straight and cylindrical for the greater part of its length, which appears in some individuals to have reached 20 to 25 cm. Occasionally marked reduction of the diameter of the corallum in the distal direction has been seen. The diameter of the adult cylindrical portion varies from about 3 to 6 cm. The corallum may occasionally exhibit rejuvenescence.

Epitheca smooth, and longitudinal ridges, though present, are not always pronounced. Annular growth-swellings of the corallum may sometimes occur, even at an early stage.

Calice.—One small specimen, from the D_2 beds at Llangollen, shows the gently sloping walls of a portion of a shallow calice, into which the major septa project as ridges for a distance of about 1 mm.

Internal Characters.

(*a*) Horizontal Sections.

Septa.—Major and minor septa are present. The number of major septa present at the adult stage is usually about 50 to 54. At certain of the earlier stages some of the major septa reach the centre, later they retreat, leaving a tabulate area, varying from 0·5 to over 1 cm. in width, exposed in the central portion of the section. Stereoplasmic thickening may affect the inner portions of all the major septa within the theca; but usually the septa on the cardinal side of the coral are the more greatly thickened. At certain of the early stages the cardinal and counter-septa may be long; at the adult stage these septa are shorter than the remaining septa. The unthickened prolongations of the major septa, which traverse the extrathecal zone up to the epitheca, frequently are slightly sinuous.

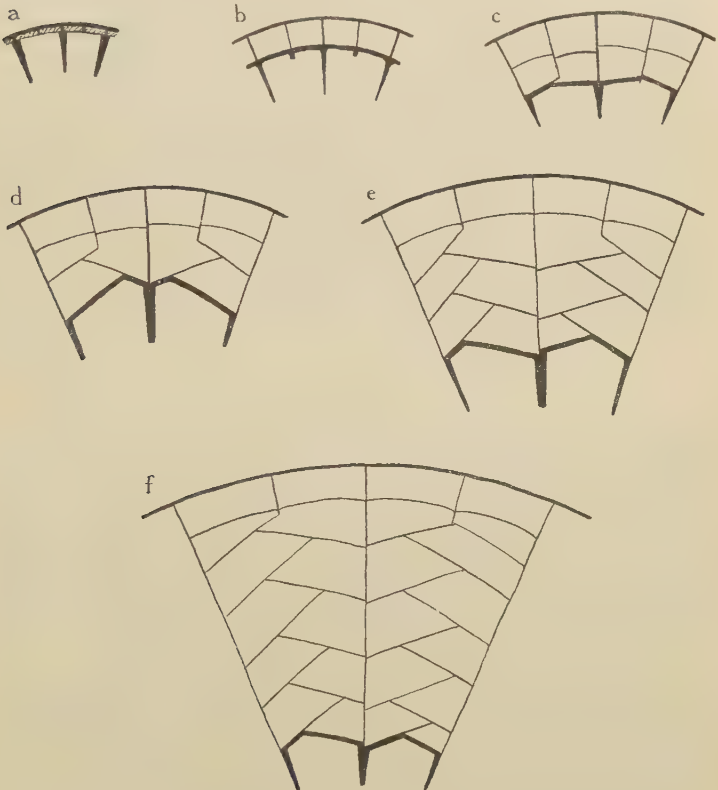
The minor septa appear before theca and epitheca can be differentiated (see Pl. XXVIII, figs. 1 *a* & 1 *b*). They remain short throughout the life of the coral. In the adult stage, if the dissepimental tissue has had freedom for growth, the minor septa do not penetrate the inner rings of dissepiments, but cross only two or three of the peripheral rings, thus giving to the major septa the appearance of being well spaced.

Fossulæ.—A cardinal fossula can be discerned at all stages of growth. It is always shallow, and is sometimes difficult to detect when the cardinal septum is long. The addition of septa is much slower in the earlier stages at the cardinal fossula than it is at the alar fossulæ.[1] This is shown in fig. 1 *k* (Pl. XXVIII),

[1] Dr. Stanley Smith has pointed out the similar nature of the addition of the septa in the genus *Aulophyllum* (1913, p. 61).

and fig. 1 *g* (Pl. XXIX), where, for about 16 major septa added in the cardinal quadrants, 22 have been added in the counter-quadrants. The alar septa, therefore, make acute angles with the line of the axial septum in the earlier stages. The alar fossulæ disappear before the addition of septa at the cardinal fossula is completed. The change in fossular appearance consequent on the

Fig. 1.—*The development of the dissepimental tissue in* Caninia juddi (*Thomson*).



[All these figures are magnified about 3½ times.]

addition of septa at a late stage is shown in figs. 2 *a*–2 *f* (Pl. XXIX).

Tabulæ.—The tabular intersections vary greatly in outline, according to the plane at which the section cuts the tabulæ; and at the cardinal fossula they are convex towards the centre.

Dissepiments.—These are added from a very early stage within the wall of the calice. In the adult stage none of the

dissepiments, or only those which are added near the rim of the calice, are traversed by minor septa. The remainder, the inner dissepiments, meet between the major septa, producing the 'herring-bone' pattern as seen in transverse section. Small dissepiments may, or may not, be present attached to both epitheca and septa at the periphery. Extension inwards of the minor septa produces a 'rectangular' arrangement of the dissepiments (see *Campophyllum rectangulare* Thomson, 1893, pl. xviii, fig. 1).

Text-figures $1a-1f$ (p. 393) show diagrammatically the successive stages in the development of the extrathecal tissue. Large and irregularly-placed cavities are usually the result of the imperfect growth of the dissepiments, or of their subsequent destruction.

Occasionally, crowding of the dissepiments is seen near the theca, but this is by no means a constant feature. The theca is usually thickened on the cardinal side of the coral.

When the corallum is cylindrical, the width of the extrathecal zone may remain fairly constant, though more often the width of this zone varies not only at different levels in the same corallum, but also on opposite sides at the same level. Thus, minor septa may be brought up to, and even penetrate, the thecal wall on one side of the coral, where the outer zone is narrow; while several rows of dissepiments may intervene between the theca and the minor septa on the other side, because there the outer zone is wide.

(*b*) Vertical Sections.

It must be realized that the appearance of the coral in vertical section varies considerably, according to the plane at which the section is taken.

Tabulæ.—A few tabulæ extend right across the intrathecal zone; but, as a rule, the majority extend only for a part of the way across. In general the tabulæ are depressed at the theca, and tend to sag in the middle portion of the corallum. These features are shown in the partly tangential section illustrated in Pl. XXVIII, fig. 2.

In sections through the cardinal fossula and the middle of the coral the tabulæ appear more 'open,' and fewer short tabulæ are seen; fig. 4 *b* (Pl. XXVII) is a section of this kind, but here there is an approach to *Caninia juddi* var. *cambrensis* (see p. 397), in which the tabulæ are more closely set.

The average number of tabulæ for a vertical distance of 1 cm., at an adult stage, is 10.

Septa.—Where a section follows a septal plane, it can be seen that the major septa extend for some distance inwards along the upper surface of the tabulæ.

Dissepiments.—The size, shape, and arrangement of the dissepiments, as seen in vertical section, vary considerably in different portions of the extrathecal zone. The width of this outer zone at an adult stage rarely exceeds 1 cm.; but it is subject to variation, especially on the rejuvenescence of the coral.

Ontogeny.

The youngest developmental stage observed is an early neanic stage. At the beginning of this stage and of a later neanic stage certain of the major septa reach, or approximate to, the centre of the corallum. At the close of each of these stages a retreat of the major septa from the centre takes place.

The Early Neanic Stages, N_1.

(*a*) 'Zaphrentoid' stage (Pl. XXVIII, fig. 1 *c* & Pl. XXIX, fig. 1 *a*).—There is a Zaphrentoid grouping of the septa, some of which reach the middle of the corallum.

(*b*) Intermediate stage (Pl. XXVIII, figs. 1 *a*, 1 *b*, 1 *d* & Pl. XXIX, fig. 1 *b*).—The majority of the septa have retreated from the centre, but the axial septum remains continuous across the corallum.

(*c*) 'Amplexoid' stage (Pl. XXVIII, fig. 1 *f* & Pl. XXIX, fig. 1 *c*).[1]—All the septa are distinctly shortened, though the counter-septum may remain longer than the rest, and give a 'Lophophylloid' appearance to the section.

The Late Neanic Stages, N_2.

(*a*) Early 'Caninoid' stage (Pl. XXVIII, figs. 1 *e*–1 *j* & Pl. XXIX, figs. 1 *d*–1 *f*).—This may be regarded as a repetition of the Zaphrentoid stage (N_1 *a*), in which the major septa do not quite reach the centre. Septal thickening is pronounced.

(*b*) Later 'Caninoid' stage (Pl. XXVIII, fig. 1 *k* & Pl. XXIX, figs. 1 *g* and 2 *a*–2 *d*).—Accompanying the increase in width of the corallum as a whole, the major septa have retreated, leaving exposed a more or less wide central tabulate area. The counter-septum may be long. The cardinal fossula, although shallow, is well defined.

The ephebic stage (Pl. XXVII, figs. 1, 3 *a*, 3 *b*, 4 *a* & 4 *b*, Pl. XXVIII, fig. 2, & Pl. XXIX, figs. 2 *e*, 2 *f*).—The features shown at this the adult stage have already been described.

[1] An Amplexoid stage occurred between the figured sections 1 *b* and 1 *c* (Pl. XXVIII). The terms 'Zaphrentoid', 'Amplexoid', and 'Caninoid' could, for the present purpose, be replaced by 'stage with long septa', 'stage with short septa', and 'more advanced stage with long septa' respectively, although the grouping of the septa is also taken into account. Exact equivalence of the Zaphrentoid and Amplexoid stages with *Zaphrentis* and *Amplexus* is ruled out by the presence of an extrathecal zone, which accompanies the later occurrence of these stages (see Pl. XXVIII, fig. 1 *f*).

The gerontic stage.—In individuals of some length, accompanying decrease in the diameter towards the distal end of the corallum, and the thinning of the septa, the outer zone becomes narrower, the extrathecal prolongations of the major septa are destroyed, and large dissepiments result. The coral then somewhat resembles in horizontal section '*Campophyllum*' *caninoides* Sibly [1] (1906, p. 368 & pl. xxxi, fig. 2 *b*).

Rhythmic Succession of Stages.

In the early stages this is a marked feature. Examination of the figured sections of these stages (Pl. XXVIII & Pl. XXIX) will show that a stage with long septa gradually gives place to a stage with short septa; and this is immediately followed by one with long septa, and so on. The rhythmic succession is not merely confined to septal length, but also to the disposition of the septa. Mr. R. G. Carruthers has shown that in *Caninia cornucopiæ* Michelin, the '*dumonti*' stage with long septa gives place to the 'Amplexoid' stage with short septa when the corallum becomes cylindrical (1908, p. 163). *C. juddi* (Thomson) appears to have adopted definitely this rhythmic succession of stages in its early life, irrespective of the shape of the corallum: that is, the intercalation of one or more 'Amplexoid' stages with short septa in the coral's early life appears to be a specific character.

Rejuvenescence.

This sometimes occurs towards the close of the neanic stage, or at the beginning of the ephebic stage: that is, when the corallum has attained its cylindrical shape, and the addition of new septa has ceased. An increase in the width of the extrathecal zone, at the expense of a decrease in the diameter of the intrathecal zone, results. For the same number of septa, the diameter of the intrathecal area, in an individual which has undergone rejuvenescence, usually remains less than that of one in which no such rejuvenescence has taken place.

Local Development.

The corals showing the neanic stages 1 *a*–1 *k* (Pl. XXVIII) & 1 *a*–1 *g* (Pl. XXIX) respectively might be judged by some authorities to belong to different species, and at first I was inclined to regard them as being homœomorphic. I now believe that they illustrate a case of the parallel development of the same species in different environments.[2] The specimen shown in

[1] These features may be the result of pathological causes, and may not be ontogenetic in their nature: but they offer an explanation to account for records of the presence of *C.* aff. *caninoides* in the Upper *Dibunophyllum* beds (see Sibly, 1908, pp. 44, 46).

[2] Allowance must always be made for what Dr. Stanley Smith has termed the 'individuality' of a coral (1906, p. 238). He found that in *Lonsdaleia* different development could be observed, even in individuals of the same colony.

Pl. XXVIII was obtained from a matrix of pure ‘knoll’-limestone, while that shown in Pl. XXIX was embedded in tough calcareous shale. The essential difference between the two corals appears to be the greater number of septa for the same diameter of corallum during the earlier stages of the coral's habitat in the muddy sea. In both, the same rhythmic succession of stages can be followed, and in both the final expression in the ephebic stage is the same (see Pl. XXVII, fig. 3 *a* & Pl. XXIX, figs. 2 *e*, 2 *f*).

Preservation.

This species is sometimes found in pure limestone as in a ‘knoll’-fauna; but it is usually obtained embedded in argillaceous limestone, or in calcareous shale. The earlier-formed portion of the corallum is usually absent (it probably often decayed before the life of the coral ended). When shale is the enclosing rock the adult portion of the corallum is frequently crushed. A great part of the study of the development of the species had therefore to be carried out on fragments of coralla varying in length and exhibiting ‘overlapping’ stages of growth. The vacant spaces left after the removal of the soft tissue are frequently filled with mud: this obscures the finer tabulæ, and causes the obliteration of the thin inner prolongations of the major septa along the superior surfaces of the remaining tabulæ, producing a ‘Campophyllid’ effect, as seen in horizontal section. When this masking of detail is accompanied by the destruction of the extrathecal tissue, a horizontal section has a ‘Calophyllid’ or ‘Amplexoid’ appearance at certain stages.

Distribution.—See under *C. juddi* var. *cambrensis*, p. 398.

CANINIA JUDDI (Thomson) var. CAMBRENSIS nov.

Type-specimen.—That figured in Pl. XXX, figs 1 *a*–1 *c*, from the Carboniferous Limestone (D_2), Treflach Wood, near Oswestry. Preserved in the Sedgwick Museum, Cambridge.[1]

External Characters.

These are similar to those described for *C. juddi*. The proximal end is cornute; the cylindrical portion is usually of greater diameter for the same number of septa than in *C. juddi*, and may be slightly tortuous. No specimen yet examined has shown rejuvenescence.

Internal Characters.

In general, the characters are similar to those of the species itself.

(*a*) Horizontal Sections (Pl. XXX, figs. 1 *a* & 2).

Septa.—The major septa on the cardinal side are considerably thickened within the theca, even at the adult stage (see Pl. XXX,

[1] Another typical specimen is No. Af. 2829 of the Geological Survey, Jermyn Street, from Puffin Island, Anglesey (D_2).

fig. 1 *a*). The number of major septa for a diameter of 3 to 4·5 cm. for the intrathecal area is usually 48 or 49, but may reach 56. The minor septa are usually shorter than in the species, and often project as mere denticles from the epitheca.

Dissepiments.—The shortness of the minor septa results in the 'herring-bone' pattern extending from the theca almost to the epitheca. The extrathecal zone may attain a width of 1 cm. or slightly more.

Tabulæ.—The tabular intersections indicate a fairly long, narrow, cardinal fossula, and show the tabulæ to be close set. The central exposed tabulate area may attain a width of 1·5 cm.

(*b*) Vertical Sections (Pl. XXX, figs. 1 *b* & 1 *c*).

The varietal distinction is based mainly on the appearance of the coral in vertical section. In sections through the fossula and middle of the coral (Pl. XXX, fig. 1 *b*), the tabulæ are more closely set than in *Caninia juddi* itself; the short tabulæ are not so arched; and, in general, the tabulæ appear flat in the centre and depressed near the theca. In a vertical distance of 1 cm. the average number of tabulæ is 15.

From the occurrence of this coral in North Wales and the Welsh Borderland, and its close resemblance to *C. juddi* (Thomson), I suggest that it be named *Caninia juddi* var. *cambrensis*.

Distribution of *C. juddi* (Thomson) and *C. juddi* var. *cambrensis* nov.

The species *C. juddi* (Thomson) as here defined, and its variety *cambrensis* are found in association. Their distribution appears to be confined to the Upper *Dibunophyllum* Zone (D_2), although they may also form part of the D_2–D_3 fauna in such regions as North Wales, where there is faunal overlap.

North Wales.—G. H. Morton (1877, 1883, 1886, 1897, 1901) recorded *Zaphrentis cylindrica* Scouler, from various horizons in the Carboniferous Limestone of North Wales; but an examination of his collection in the British Museum (Natural History) and the study of material collected from his localities prove that he included under this name *C. juddi* and its variety *cambrensis*, together with other corals which resemble *C. patula* in their development.

Dr. Wheelton Hind and Mr. J. T. Stobbs (1906, p. 392) visited Morton's localities, and recorded *Campophyllum derbiense* Vaughan MS., from a quarry at Prestatyn, and *Campophyllum* aff. *murchisoni* Edwards & Haime, from Trellach Wood (1906, p. 450); the latter is the variety *cambrensis* of the present paper.

Arthur Vaughan mentioned the occurrence of the species (as *C. derbiense*) in the Oswestry and Corwen districts (1915, p. 28). While it is fairly common in the D_2 beds near Oswestry, repeated search at Corwen has failed to disclose it.

Dr. E. Greenly (1919) records *Caninia juddi* (Thomson) as *Campophyllum* sp. nov., in his D_2 faunal list from Anglesey. He mentions in the appendix (1919, App. ii, p. 924) that this form is identical with *C. derbiense* Vaughan MS. Examination of several of the Geological Survey specimens from Anglesey and Puffin Island proves this identification to be correct.

C. juddi (A) and its variety *cambrensis* (B) have been collected from the following localities:—The Llanymynech (A) and Treflach Wood (A, B) quarries in the Oswestry district; the Eglwyseg escarpment (A, B); the limestone north of the Llanelidan fault near Llandegla (B), and from Halkyn Mountain (B) near Holywell. The Anglesey specimens come from Puffin Island (B); Bettws (A); near Llanallgo (A); near Tyn-y-gongl (A & B) and the cliffs near Llangoed (A).

North-Western Province.—Collecting in this province has been limited to the Settle and Grassington Districts, but to Prof. E. J. Garwood I am indebted for a suite of Caninoid corals from various horizons in the North-Western Province. Out of this collection three specimens, one from the Lower *Lonsdaleia* Beds of Penyghent, one from the Simonstone Limestone, Ingleborough, and one from the Langcliffe Plateau, near Settle, belong to the species *C. juddi*. From Wedber Knoll, my acquaintance with which I owe to the kindness of Miss E. Goodyear, I have collected several specimens of *C. juddi* and one of the variety *cambrensis*, while other specimens of the species have been obtained from the Lower *Lonsdaleia* Beds at Coldstones Quarry, near Greenhow Village, and at Kettlewell.

The Midlands.—*C. derbiense* Vaughan is recorded from the D_2 beds of Derbyshire and North Staffordshire by Principal T. F. Sibly (1908), who remarks (p. 48) that the species is generally distributed, though rarely of common occurrence. Of the two specimens sent to me by Dr. Sibly and recorded by him in his paper (1908) as *C. derbiense*, one from Moneyash proved to be the new variety *cambrensis*, while the other is the new species *Caninia buxtonensis* described on p. 400.

Wheelton Hind, in his account of the geology of Staffordshire in 'Geology in the Field' (1910), includes *Campophyllum derbiense* in his lists of D_2 fossils from Waterhouses (p. 570) and from Newbould, near Astbury (p. 574).

The specimens that I have collected from this area were obtained principally from the Matlock district. They were confined to the D_2 beds, and, though poorly preserved, appear to be referable either to the species *Caninia juddi* or to its variety, more probably the latter.

In Leicestershire Dr. L. M. Parsons found '*Campophyllum*' *derbiense* Vaughan, in the Ticknall and Breedon Cloud sections, accompanied by typical D_2–D_3 fossils (1918).

South-Western Province.—Specimen R. 16707 of the Percival Collection in the British Museum (Natural History) is labelled 'S. W. England', and is a form of *C. juddi* (Thomson)

characterized by a wide extrathecal zone and fairly long minor septa. Two specimens, C. 4214, in the Bristol Museum, from the Avon Gorge, appear to belong to *Caninia juddi*. Vaughan also mentioned the occurrence of his species *Campophyllum derbiense* in the South-Western Province (1915, p. 25).

Scotland.—J. Thomson's species *C. juddi* and its synonyms appear to come from an Upper Viséan horizon (1893).

Belgium.—Vaughan recorded *Campophyllum* cf. *derbiense* from the V_{2c} beds of Warnant in the Anhée Basin. Prof. G. Delépine also gave a doubtful record of *C. derbiense* from near Namur, Samson section (1909, p. 429; but see Delépine 1911, p. 117).

Russia.—A. Stückenberg figures and describes from Central Russia (1904), and from the Ural and Timan (1895), several specimens which appear to resemble *C. juddi* Thomson, as here defined.

Caninia buxtonensis sp. nov.

Type-specimen.—That figured in Pl. XXX, figs. 3 *a*–3 *f*, from the *Dibunophyllum* Zone of the Carboniferous Limestone, Park Hill (Derbyshire). Preserved in the Sedgwick Museum, Cambridge. Collected by Principal T. F. Sibly.

External Characters.

Corallum.—Simple, cylindro-conical; probable length=about 6 to 8 cm. Width of adult cylindrical portion=4 cm. Rejuvenescence occurs near the base of the adult cylindrical portion.

Epitheca.—Fairly smooth, showing faint but definite longitudinal ridges, and closely-set annular striations.

Calice indefinite, probably fairly deep.

Internal Characters.

(*a*) Horizontal Sections (Pl. XXX, figs. 3 *a*–3 *d*, & 3 *f*).

Septa.—For a total diameter of 4 cm., or a diameter of the intrathecal area of 2·2 cm., 48 major septa are present. The stereoplasmic thickening of the major septa, characteristic of the late neanic stages (Pl. XXX, figs. 3 *a*–3 *c*), is greatly reduced as the ephebic stage (Pl. XXX, fig. 3 *f*) is attained. Where the septa are thickened, the intrathecal thickening may be prolonged for some distance into the extrathecal area. The cardinal septum is short and weakly developed. The central septa-free tabulate area at the adult stage has a diameter of about 1·2 cm.

Tabulæ.—Tabular intersections usually show the tabulæ to be irregular. The inward shift of the tabular intersections, indicating the depression of the tabulæ at the cardinal fossula, becomes less marked as growth proceeds.

Dissepiments.—The nature of the dissepiments is characteristic of the species. The extrathecal zone, from an early stage onwards, can be divided into an inner area traversed by the major

septa, between which the dissepiments meet to give the 'herring-bone' pattern, and an outer area of large dissepiments, concave outwards, not crossed by septa. Hence, the dissepimental structure of this zone possesses the essential features of both *Caninia cylindrica* Scouler, Salée and *C. juddi* (Thomson) emend. Where the outer area of large dissepiments is reduced in width (see Pl. XXX, fig. 3 *d*), the horizontal section of the coral closely resembles that of *C. juddi*. The theca is not thickened in the adult stage; but its position is indicated by the crowding together of the innermost dissepiments.

(*b*) Vertical Sections (Pl. XXX, fig. 3 *e*).

Tabulæ.—In the sections through the cardinal fossula and the centre of the coral the tabulæ are well defined. On an average 12 tabulæ are present for a height of 1 cm. They are considerably depressed at the cardinal fossula, and less so on the counter side of the coral. Some of the tabulæ extend right across the intrathecal area, while others extend for a shorter distance. As in *C. juddi*, there is a tendency for the tabulæ to sag in the central portion of the corallum.

Dissepiments.—These, as seen in vertical section, are in general less curved than in *C. juddi*, and the obliquely elongate inter-dissepimental loculi approximate more closely in shape to those of *C. juddi* var. *cambrensis*.

Ontogeny.

It is unfortunate that no stage earlier than the late neanic stage is known. At this stage (Pl. XXX, figs. 3 *a*–3 *c*) the major septa are considerably thickened within the theca, which usually is slightly thickened. As in *C. juddi*, more septa have been added at the alar fossula than at the cardinal fossula. The cardinal fossula is of the 'open' type, and is marked by the short thickened cardinal septum and the pronounced inward curvature of several tabular intersections in the tabulate area. The remaining tabular intersections are very irregular, and show the tabulæ to be closely set. The minor septa are spasmodic in their occurrence, and appear readily to give place extrathecally to dissepiments showing the 'herring-bone' pattern. The dissepiments at an early stage are distinctly irregular, and the narrow outer zone may either be traversed by the major septa, or large curved dissepiments, outside of which the septa do not pass, may occur peripherally.

Distribution.—The holotype was sent to me by Principal T. F. Sibly, who collected it at Park Hill, just within the western border of Derbyshire, and about 4 miles south-south-east of Buxton. After this, the nearest town of importance, I suggest that the species be named. Dr. Sibly informs me that the coral 'occurred in association with a large *Carcinophyllum* in the white limestone interbedded with the white brachiopod-bearing lime-

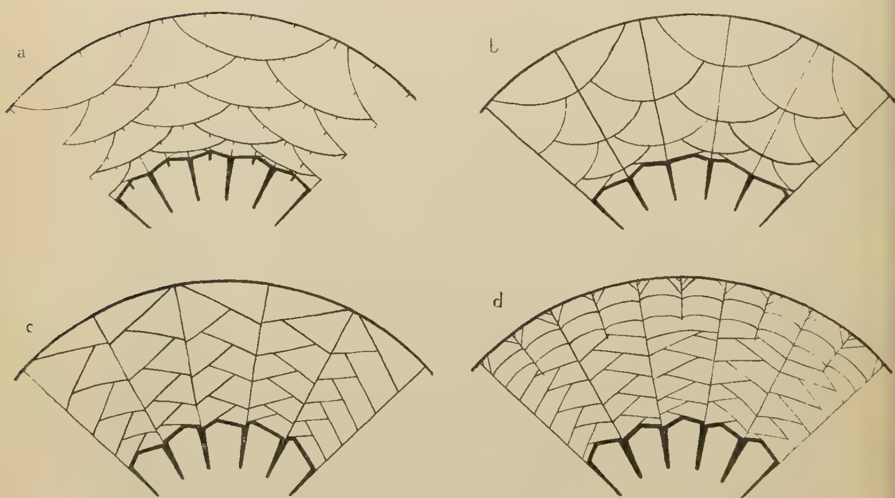
stones of the famous Park Hill locality,' which he believes may belong to D_2, and at least not to an horizon lower than D_1.

Remarks.—The species in its development, so far as it is known, resembles that of *C. juddi* Thomson, and the features which it presents warrant its inclusion in the genus *Caninia*. It is interesting to note that some of the characteristics of *C. buxtonensis*, as, for example, the dissepimental development and structure, are what might be expected in a species from which *C. juddi* and its allies might have arisen. It is chiefly for this reason that I have had the temerity to establish a species from one specimen, after search for further similar material in Derbyshire has failed.

Notes on the Dissepiments.

Dr. A. Vaughan divided his 'Campophyllids' into 'Caninid' and 'Clisiophyllid' sections (1906, p. 139), the principal features

Fig. 2.—*Probable evolutionary stages in the derivation of the 'herring-bone' type of dissepimental arrangement seen in* C. juddi (2 *d*), *from the Caninoid type characteristic of* C. cylindrica (2 *a*).



[All the above figures are magnified about twice.]

separating these sections being the arrangement of the dissepiments. *Caninia cylindrica* Scouler, Salée (1910) has an extrathecal zone identical with that possessed by the former class, while *C. juddi* (Thomson): that is, *Campophyllum derbiense* Vaughan, exhibits the 'Clisiophyllid' arrangement. Text-figures 2 *a*–2 *d* show diagrammatically the probable relationship of the two dissepimental arrangements.

The earlier forms of *Caninia cylindrica* Scouler, Salée, have large dissepiments in the outer zone, which is not radiated, or only radiated in part, by septa (text-fig. 2 *a*). The same dissepimental arrangement, with the major septa continuous across the outer zone, is shown in text-fig. 2 *b*. Straightening-out of the dissepiments produces the 'herring-bone' pattern seen in fig. 2 *c*. In *C. juddi* Thomson (fig. 2 *d*) the inner portion of the extrathecal zone shows the 'herring-bone' (Clisiophyllid) pattern; while in the peripheral portion minor septa are present, and the arrangement of the dissepiments is more or less 'rectangular'.

In *C. buxtonensis* a dissepimental arrangement is seen, which, from the very commencement of the formation of an extrathecal zone, combines the features of the dissepimental zones of both *C. cylindrica* and *C. juddi*.

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EXPLANATION OF PLATES XXVII–XXX.

PLATE XXVII.

Fig. 1. *Caninia juddi* (Thomson). Slightly oblique transverse section of very late neanic stage. Geological Survey specimen, No. Af. 2025. Natural size. D_2. Tyn-y-gongl. Anglesey (Museum of Practical Geology, Jermyn Street).

2. *Caninia juddi* (Thomson). (*Campophyllum derbiense* Vaughan.) Ephebic, or very late neanic stage. Transverse, partly oblique, section, collected, cut, and presented to the British Museum by Dr. A. Vaughan, B.M. No. R. 15307. Natural size. D_2. Llangollen. Photographed by the British Museum (Natural History).

Figs. 3 *a* & 3 *b*. *Caninia juddi* (Thomson). Neotype. Sections from the same corallum. Fig. 3 *a*. Transverse section at the ephebic stage. Fig. 3 *b*. Vertical section through the cardinal fossula and the middle of the coral (note the fractured tabulæ and the irregularity of the dissepiments). Natural size. D_2. Wedber Knoll, Malham (Sedgwick Museum, Cambridge).

4 *a* & 4 *b*. *Caninia juddi* (Thomson). (Convergent towards *C. juddi* var. *cambrensis* nov.) Fig. 4 *a*. Transverse section. Fig. 4 *b*. Vertical section of the same corallum at the ephebic stage. Natural size. Specimen slightly tortuous. Collected by Prof. E. J. Garwood. D_2. Lower *Lonsdaleia* Beds. Old Ing, Penyghent (Sedgwick Museum, Cambridge).

PLATE XXVIII.

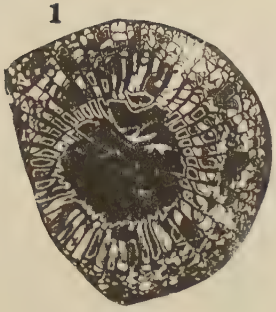
Figs. 1 *a*–1 *k*. *Caninia juddi* (Thomson). Transverse sections from one specimen. Figs. 1 *a*–1 *g*. Early neanic stages. Figs. 1 *h*–1 *k*. Late neanic stages. All × 2. D_2. Wedber Knoll, Malham (Sedgwick Museum, Cambridge).

Fig. 2. *Caninia juddi* (Thomson). Vertical section, cut tangentially, of an adult portion of the same corallum. In the middle of the section the septal ends and thickened tabulæ can be seen. Natural size. D_2. Wedber Knoll, Malham (Sedgwick Museum, Cambridge).

PLATE XXIX.

Figs. 1 *a*–1 *g*. *Caninia juddi* (Thomson). Transverse sections from one specimen. Figs. 1 *a*–1 *c*. Early neanic stages. Figs. 1 *d*–1 *g*. Late neanic stages. All × 2. Llanymynech Hill, near Oswestry (Sedgwick Museum, Cambridge).

1



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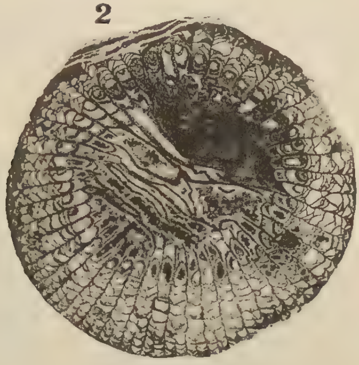

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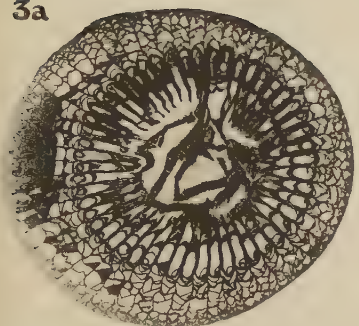

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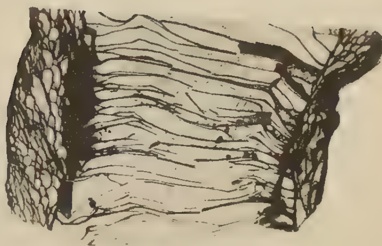

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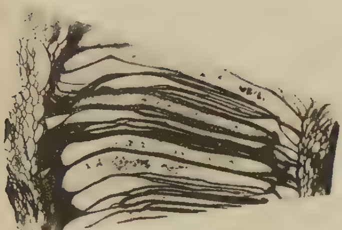
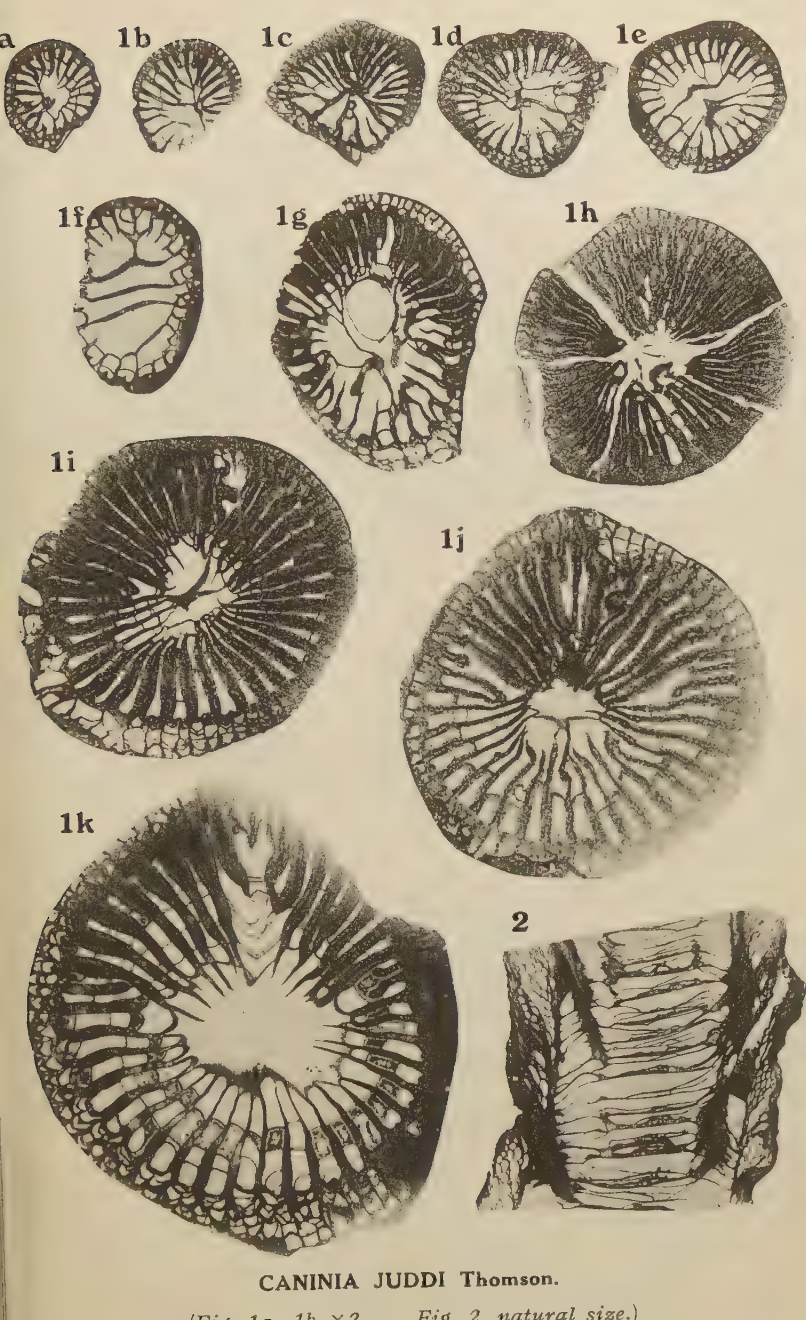


4a

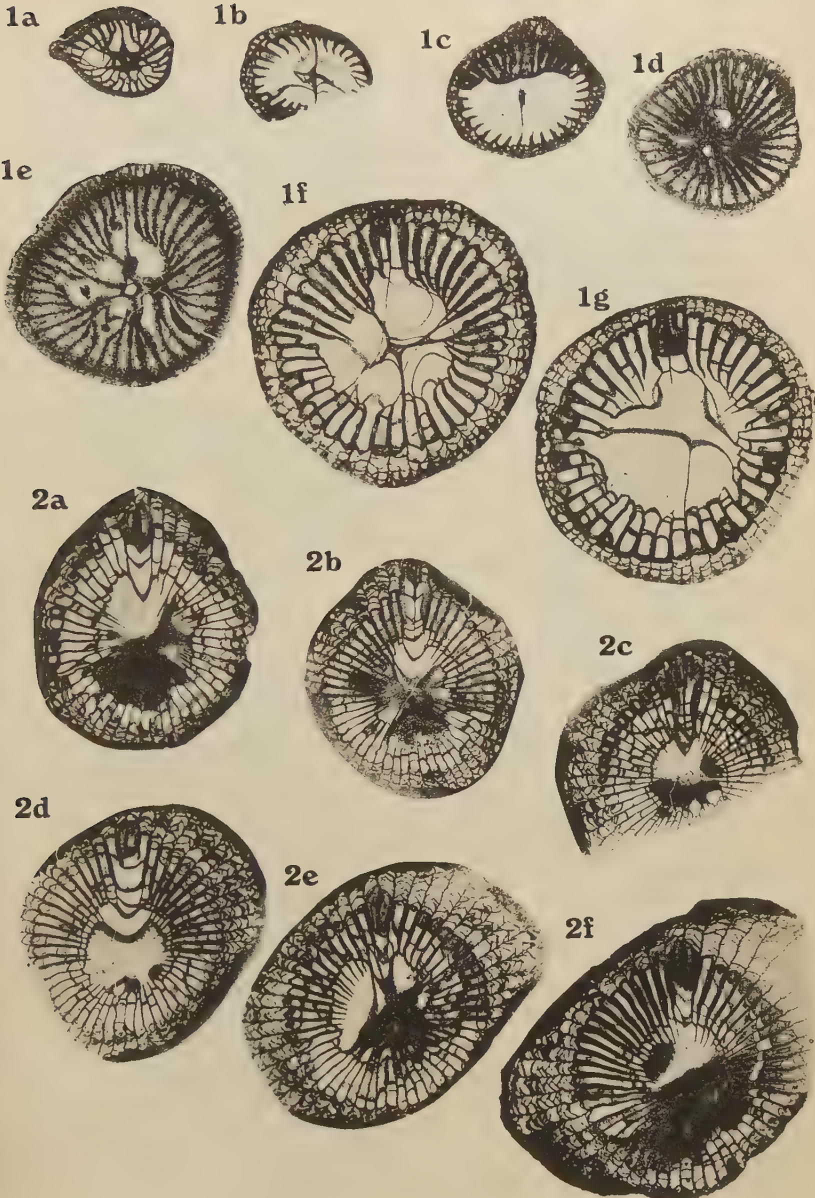
CANINIA JUDDI Thomson.

(All sections are of the natural size.)



CANINIA JUDDI Thomson.

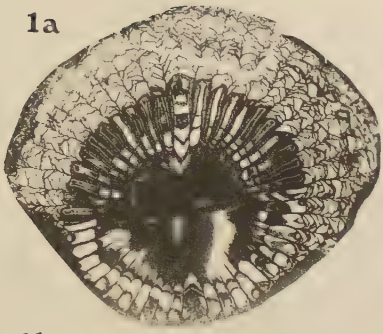
(Fig. 1a—1k ×2. Fig. 2, natural size.)



CANINIA JUDDI Thomson.

(*Figs. 1a—1g* ×2. *Figs. 2a—2f, natural size.*)

1a



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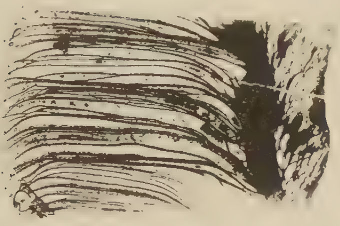

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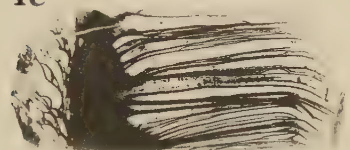

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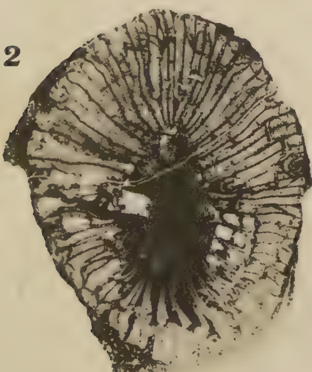
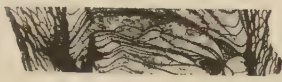


3f

3e



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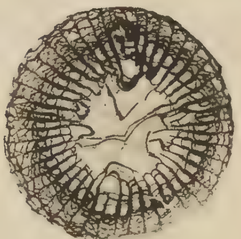

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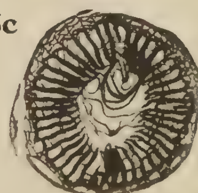

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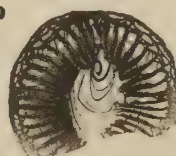

3a

CANINIA JUDDI var. CAMBRENSIS. C. BUXTONENSIS.

(*Figs. 1a—1c & 3a—3f, natural size. Fig. 2 ×2.*)

Figs. 2 *a*–2 *f*. *Caninia juddi* (Thomson). Transverse sections from 1 inch of a corallum, showing fossular changes consequent on the addition of new septa. Natural size. D_2. Treflach Wood, near Oswestry (Sedgwick Museum, Cambridge).

PLATE XXX.

Figs. 1 *a*–1 *c*. *Caninia juddi*, var. *cambrensis* nov. Holotype. Sections from one corallum. Fig. 1 *a*. Transverse section at the ephebic stage. Fig. 1 *b*. Vertical section through the septum flanking the cardinal fossula. Fig. 1 *c*. Vertical section through the cardinal fossula and the centre of the coral. The dissepimental tissue on the counter side had been destroyed. Natural size. D_2. Treflach Wood, near Oswestry (Sedgwick Museum, Cambridge).

Fig. 2. *Caninia juddi*, var. *cambrensis*. Transverse section at the neanic stage. The dissepimental tissue has been destroyed. × 2. D_2. Treflach Wood (Sedgwick Museum, Cambridge).

Figs. 3 *a*–3 *f*. *Caninia buxtonensis* sp. nov. Holotype. Figs. 3 *a*–3 *d*. Transverse sections of late neanic stages. Fig. 3 *e*. Vertical section through the cardinal fossula and the centre of the coral at the ephebic stage. Fig. 3 *f*. Transverse section at the ephebic stage. All the sections are of the natural size and from the same specimen. Collected by Principal T. F Sibly, and section 3 *d* cut by him. D_1 or D_2? Park Hill, Derbyshire (Sedgwick Museum, Cambridge).

DISCUSSION.

The PRESIDENT (Dr. J. W. EVANS) asked whether any of the American palæontologists had contributed to the literature of the evolution of Lower Carboniferous corals.

Prof. W. G. FEARNSIDES congratulated the Author on his presentation of the first fruits of the course of research to which he had been encouraged by an award from the Daniel-Pidgeon Fund. When the Author first observed in the limestones about Llangollen the forms of *Caninia* which he had now described, he had supposed that they were members of the *C. cylindrica* group, which had survived, and under special local conditions flourished at a period later than their proper zone. His further work had shown that it was not the corals, but only their names that were exotic, and the present paper was mainly a clearing of the decks for the presentation of the Author's later zonal work. The speaker enquired whether the Author was of opinion that the new species that he had described were likely to be of stratigraphical value as indicators of a definite limestone zone.

Dr. J. A. DOUGLAS congratulated the Author on the result of his investigations, but deprecated the use of the term 'Amplexoid phase' to indicate a stage of ontogenetic development when the coral showed a waning vitality. The suggestion seemed to be implied that *Amplexus* belonged to a phylogenetic series, of which *Zaphrentis* and *Caninia* were earlier members. This was not in accordance with field evidence. *Amplexus*, in the speaker's experience, was rare in the normal type of Carboniferous Limestone. It occurred, however, in great profusion in the *Syringothyris* Zone of Western Ireland, which, like the Waulsortian phase

of Belgium, must have been deposited under quite abnormal conditions. Its mode of growth was entirely distinct from that of *Caninia*. No dissepiments were developed, and the coral grew rapidly by a series of tabular 'jumps', which were so frequent that only rudimentary septa had time to form. Such a structure clearly denoted vigorous growth and adaptation to peculiar conditions and environment, and in no way suggested a waning vitality. He, therefore, advocated the substitution of the term 'Campophylloid', in place of Amplexoid as used by the Author.

The SECRETARY read the following contribution to the Discussion sent by Dr. W. D. LANG:—

'I am disappointed at not being able to be present at the reading of this paper. Having seen the Author's work, I think that he is to be congratulated upon the thoroughness of his investigation and upon the several interesting points which he has noticed concerning the morphology, ontogeny, and bionomy of the described corals.

'The periodic repetition of stages during ontogeny is of particular interest. Very generally speaking, and considering for the moment only the distribution of the major septa as seen in transverse section, we may say that in the Carboniferous Rugose Corals there is a tendency during both ontogeny and phylogeny for the septa, which at first meet at the centre (Zaphrentoid phase), to shorten distally and so to break away from the centre (Caninoid phase), and, finally, to become very short, or Amplexoid. The Author finds that not only is this trend carried out in the ontogeny of *Caninia juddi* as a whole, but that a period of Zaphrentoid, Caninoid, and Amplexoid phases is run through early in the ontogeny, and is followed by a second similar period at a later age. I would suggest that the Amplexoid phase reflects a waning of the coral's vitality: that when it occurs early in the ontogeny, the cause may be environmental—it may be the end of a growing season when temperature and vitality are low or food-supply scanty: that, on the renewal of favourable conditions, vigorous growth recommences; and then the coral recapitulates first a Zaphrentoid and then a Caninoid phase under the new conditions, and with a larger and more complex skeleton, just as corals (for instance, *Parasmilia*) tend to recapitulate at a rejuvenescence (which is allied, I believe, to branching), and as branching organisms tend to recapitulate at a branch. The ontogeny is thus seen to present a life-period with secondary similar and seasonal periods rhythmically repeated upon it. I understand that the Author does not suggest a rejuvenescence occurring after the first Amplexoid stage: if so, there would simply be recapitulation at rejuvenescence; but, if not, there might well be renewed seasonal growth at that point.'

The AUTHOR stated, in reply to the President, that he was unaware of the existence of any American work dealing with the corals in the study of which he was engaged.

With regard to the zonal value of the corals in question, the Author said that *Caninia juddi* (Thomson) emend. ranged throughout D_2 and possibly up into the lower part of D_3.

He was pleased to find that Dr. Lang considered that certain phenomena found by him (Dr. Lang) to exist in the development of *Parasmilia* might be in harmony with the periodic repetition of stages seen in the development of *Caninia juddi* (Thomson). Dr. Lang's suggestion that this periodic repetition of stages might be due to vigorous growth on the recurrence of favourable conditions was a valuable one. As the Author had found a similar periodic repetition to occur at an early stage in a species of

Amplexus, which was not reflected outwardly in the shape of the corallum, he had no doubt that there was no rejuvenescence in the usually accepted sense, although rejuvenescence might occur in the sense suggested by Dr. Lang.

The Author agreed with Dr. Douglas that the term 'Amplexoid' was often assigned to a stage not showing all the characteristics of a true *Amplexus*; but he pointed out that, if the very ill-defined genus *Campophyllum* were retained, the term 'Campophylloid' should be restricted to the stages showing a well-developed dissepimental zone, which in *Amplexus* was absent. Confusion could only be avoided by giving a strict definition of the sense in which the various descriptive terms were used.

17. Descriptions *of* Gasteropoda, *chiefly in* Mrs. Robert Gray's Collection, *from the* Ordovician *and* Lower Silurian *of* Girvan. By Jane Longstaff (*née* Donald), F.L.S., F.G.S. (Read March 12th, 1924.)

[Plates XXXI–XXXVIII.]

Contents.

I. Introduction.

Since this contribution to the knowledge of the more ancient Palæozoic gasteropoda is primarily concerned with those from the Girvan district, contained in Mrs. Gray's magnificent collection, reference is made to others only where they afford further information concerning structure or distribution. Forty-one forms are dealt with, seven of which have been described and one named in MS. by previous authors.

Twenty-four species and one variety from the same district were described and figured by me in papers read before this Society in the years 1899, 1902, 1905, and 1906. Of these twenty-one species and a variety belong to genera referred to the Pleurotomariidæ; and now twenty-five species and a variety are added to this number.

I am following Dr. E. O. Ulrich in his classification of the family, only making exception in the case of *Omospira*. He considers this genus more akin to *Raphistoma* Hall. It is, however, distinguished by having a sinus in the outer lip at the periphery, also a band on most of the whorls; this latter is never present in *Raphistoma* according to Hall, and also according to Dr. Ulrich himself. So far, I have not met with any specimens bearing the characteristics of *Raphistoma* sensu stricto in the Scottish Ordovician. The internal moulds of certain forms have been mistaken for that genus; but, where the structure is preserved, as will be pointed out, there can be no doubt that they belong to *Liospira* Ulrich.

In what degree these ancient forms are really related one to the other and to the recent *Pleurotomaria* remains to be proved. The state of preservation makes it difficult or impossible in many cases to discern whether there existed a true slit or merely a sinus in the outer lip; all, however, have a band on the whorls. Elongated shells, such as *Hormotoma*, *Donaldiella*, and *Eotomaria*, which approach *Murchisonia* in form, have only a sinus;

while the typical *Murchisoniæ* (like *Pleurotomaria*) possess a slit with parallel edges, and thus have three areas of shell-deposition. *Palæoschisma* is the only Scottish Ordovician genus that appears to have a slit, while *Schizolopha* Ulrich, is the only American genus. Dr. Ulrich considers that *Phanerotrema* Fischer possessed a slit; the two species that I have seen from the Scottish Llandovery are not sufficiently well preserved to show this character very distinctly; in one specimen, however, there are indications of a slit.

I must mention that there is probably another member of the genus *Lophospira* Whitfield in the Lower Ordovician, but the specimens are too imperfectly preserved to enable one to identify it with certainty. It is a somewhat large form, of which there are two examples from Minuntion in the collection of the Misses Gray, and another from Craighead in the Royal Scottish Museum, Edinburgh.

The examination of a larger number of specimens of a shell that I described as a variety of *Lophospira bicincta* Hall under the name *scotica* Donald [1] has convinced me that the difference in form and ornamentation is sufficient to authorize us to consider it a distinct species.

In addition to dealing with the Pleurotomariidæ in my former papers, I gave figures and descriptions of three other species, one possibly referable to the genus *Aclisina*, and the others to two distinct genera of the Loxonematidæ.

I am now describing four new species belonging to three subgenera of the Loxonematidæ; two species of *Maclurea*, one of which has not been previously described; four of *Eccyliomphalus* (two new); two of *Lesueurilla* (both new); one of *Euomphalopterus* (also previously undescribed); and two of *Clisospira*, which are not only species new to science, but the genus itself does not appear to have been recorded from the British Isles before.

Mrs. Gray's collection has been acquired by the authorities of the British Museum (Natural History), and is now located there.

I am deeply indebted for the loan of specimens to the late Mrs. Gray and her daughters, also for loans and assistance in studying to Sir Arthur Smith Woodward, Dr. F. A. Bather, Prof. J. E. Marr, Dr. F. L. Kitchin, Dr. J. Ritchie, Dr. G. W. Lee, Prof. J. W. Gregory, and Miss E. D. Currie, to all of whom I would offer most sincere thanks.

In order to save space, the synonymy is restricted to only such references as are necessary for identification.

[1] Q. J. G. S. vol. lxii (1906) p. 564 & pl. xliv, figs. 3–4.

II. Description of the Fossils.

Family **Pleurotomariidæ** A. d'Orbigny.

Genus LIOSPIRA Ulrich, 1897.

Liospira disciformis, sp. nov. (Pl. XXXI, figs. 1–3.)

Diagnosis.—Shell large, discoidal, spire low, flat or slightly convex. Whorls about six, flattened convexo-concave above; periphery acutely angular, somewhat flange-like, overlapping the suture, and having a thread at the margin, in close contact with another thread or swelling on the upper part of the succeeding whorl. The greater portion of the band forms a shallow groove above the periphery; upper limit indistinct, chiefly indicated by the lines of growth; point of the sharply angular sinus situated on the peripheral thread. Lines of growth above, coarse at intervals, with finer ones intercalated, curving back very obliquely to the band; below they run first obliquely forward, then almost vertically, after which they advance in a very convex curve, and finally turn almost direct into the umbilicus. Base convex, with a wide, deep, and subangular umbilicus. Aperture triangular, nearly horizontal above, angular at the upper outer edge, convex and prominent below.

Remarks.—This species bears a considerable likeness to *Liospira* (*Helicites*) *qualteriata* Schlotheim, of which there are specimens in the British Museum (Natural History) from Reval (Esthonia), where the holotype was found. These agree with Schlotheim's description and figures, but possess additional characters not noted by him, as four adult examples show a slightly grooved band, and one bears traces of the lines of growth. *Liospira disciformis* differs in being lower and more disc-like, and in the umbilicus being wider and more angular. It resembles a specimen from Petrograd, also in the British Museum, marked *Raphistoma qualteriatum* (G. 750), which is larger and flatter than the type of that species. An exact comparison is, however, impossible, as no surface-markings are preserved. Both Lindström and Koken observed a certain amount of variation in the forms referred to *Helicites qualteriatus* Schlotheim, and the latter (1897, p. 163) named a mutation *depressa* which appears to have some resemblance to the species under discussion; but the description is limited, and there is no figure.

Internal moulds of the three species that I am here referring to *Liospira* resemble *Raphistoma*, in which genus (among others) they have previously been placed; when, however, the real structure of the shell is preserved they may readily be distinguished. The umbilicus is wider, the lines of growth sweep back more obliquely, and form a sinus at the periphery where there is a band, and the upper part of the outer lip is devoid of the sigmoidal curve characteristic of *Raphistoma*. Lindström placed *H. qualteriatus* in *Pleurotomaria*, and accurately represented the

band of a small flat form from Öland which he referred to that species (1884, pl. xiii, fig. 16).

The shape of the shell, as also the character of the band, agrees with the genus *Liospira* Ulrich, as may be seen by comparison with the figures of one of his type-species, *L. micula* (Hall) in pl. lxviii, figs. 24–29, and with *L. vitruvia* (Billings) in pl. lxix, figs. 3–8. *L. disciformis* is much larger and flatter than these species, but the lines of growth are like those of the former; while the base with its angular umbilicus is similar to that of the latter.

Holotype (Pl. XXXI, figs. 2*a*–2*d*; G. 25,329).—This specimen is partly embedded and slightly crushed, but both the upper and the under surfaces are exhibited.

Dimensions.—Greatest diameter above = 47 mm.; smaller diameter measured across the base = 42 mm. Length = about 15 mm. A larger example (Pl. XXXI, fig. 1; G. 25,328) from the same locality has the base alone exposed; its greatest width = 56 mm.

Locality.—Dow Hill (1).

Besides these, Mrs. Gray's collection contains three specimens from Balclatchie (2). One is the external mould of the upper surface of a large shell; the two others are almost perfect internal moulds of quite young examples, one of which is figured (Pl. XXXI, fig. 3; G. 25,333). The greatest width = 9 mm.; least width = 7 mm.; height = about 2·5 mm.

A large gasteropod in the Sedgwick Museum, Cambridge, from Aldons, probably belongs to this species. It is, however, merely an internal mould of which only the upper part is visible, the base being embedded; therefore it is impossible to identify it with certainty.

Horizon.—(1) Stinchar Limestone Group; (2) Balclatchie Group (Conglomerate); Lower Ordovician.

A specimen (No. M 1634 *d*) from Wallace's Cast, near Abingdon, in the collection of the Scottish branch of the Geological Survey, and two others from Tyrone in the Wyett-Edgell Collection (30,182–183) in the Museum of Practical Geology, London, may be conspecific, but they are all too much crushed for exact identification. These are referred to the Caradocian by the Geological Survey.

Liospira striatula (Salter MS.). (Pl. XXXI, figs. 4–5, & Pl. XXXII, figs. 1–2.)

Raphistoma (*striatula*) Hughes & Etheridge, 1865, 'Catal. Coll. Foss. Mus. Pract. Geol.' p. 21.

Raphistoma striatula Salter MS. 1878, 'Catal. Cambr. Silur. Foss. Mus. Pract. Geol.' p. 55.

Diagnosis.—Shell discoidal, spire low. Whorls about six, slightly convex above, more convex below, periphery angular, overlapping the suture, bearing a thread at the margin which is in contact with another on the upper part of the succeeding whorl.

Band having the greater part above the angle slightly grooved, and limited on the apical side by a thin thread. Lines of growth curving backwards very obliquely to the band, closely packed on the band, and forming a sharp point situated on the peripheral thread; crossed by exceedingly fine spiral lines. Base convex, but little produced. Umbilicus deep, of medium width, sometimes filled up by shelly matter, producing the appearance of a solid columella. Aperture obliquely oblong, angular at the upper outer margin, rounded below.

Remarks.—This species has not been described or figured previously, but was merely named by Salter in MS. and afterwards recorded in the 'Catalogue of Cambrian & Silurian Fossils in the Museum of Practical Geology.' Mrs. Gray's collection contains eight examples, all smaller and less well preserved than the type. *Liospira striatula* is distinguished from *L. disciformis* by the narrower and more slowly increasing whorls, the greater height and convexity of the base, the umbilicus being less wide, and having a more rounded margin, and by the band being more distinctly limited above. From *L. qualteriata* it differs in being flatter above, and more regularly convex below.

Among American species *L. striatula* is most like *Raphistoma* (*Maclurea*) *striatum* Emmons, but the base is lower.

Holotype (Pl. XXXI, figs. 4 *a*–4 *c*).—No. 30,181, Museum of Practical Geology, London.

Dimensions.—Length = 25 mm.; greatest width = 53·5 mm.; least width = 44 mm.

Locality and horizon.—The holotype is from Penwhapple Burn, Girvan, and is referred to the Caradocian. Mrs. Gray's specimens are from the Balclatchie Conglomerate, Balclatchie Group, and the matrix greatly resembles that of the holotype (Pl. XXXI, fig. 5, & Pl. XXXII, figs. 1–2; G. 25,334, G. 25,335, & G. 25,336). Lower Ordovician.

LIOSPIRA ÆQUALIS (Salter). (Pl. XXXII, figs. 3 & 4.)

Euomphalus qualteriatus (Schlotheim) Salter, 1848, Mem. Geol. Surv. vol. ii, pt. i, p. 356 & pl. xiv, fig. 7.

Raphistoma æqualis (*qualteriatum* Salter) Salter, 1859, 'Siluria' 3rd ed. Appendix, p. 549, Foss. 37, fig. 2.

? *Trochus ellipticus*, Portlock, 1843, 'Report on the Geology of the County of Londonderry, &c.' p. 414 & pl. xxxi, fig. 1.

Non Hisinger, 1837, 'Lethæa Suecica' p. 35 & pl. xi, fig. 1.

Diagnosis.—Shell conical, spire of moderate height. Whorls about four, flattened convexo-concave above, periphery angular and turned upwards. Base moderately convex. Umbilicus elliptical, widely open, angular at the margin. Band indicated by a groove immediately above the periphery; lines of growth sweeping back to it.

Remarks.—There are four specimens of this species in Mrs. Gray's collection; none is well preserved, and only one shows traces of the lines of growth. Salter at first erroneously identified this form with *L.* (*Helicites*) *qualteriata* (Schlotheim),

but he afterwards corrected the mistake, and named it *Raphistoma æqualis*. It is distinguished from *L. qualteriata* by its higher spire and upturned peripheral edge. The species which this most resembles is *Helicites obvallatus* Wahlenberg (1821, p. 73 & pl. iv, figs. 1, 2); but the latter has the whorls more exsert and step-like. *Trochus ellipticus* Portlock may possibly be conspecific; the type, however, is too much crushed to admit of certainty.

The band is not distinctly exhibited, and there are only traces of a groove above the periphery on two specimens; it was probably similar to that of *H. obvallatus* as figured by Lindström (1884, pl. xiii, figs. 17 & 18).

Holotype.—*Liospira (Raphistoma) æqualis* (Salter). Museum of Practical Geology, London.

Dimensions.—Length = 24 mm.; greatest width = 47 mm.; least width = 36 mm.

Locality.—Bird Hill, Llandeilo.

Horizon.—Caradocian.

A shell from Girvan is associated with the type, but it appears to me distinct: there is no trace of the upturned margin, and it is merely an internal mould, having the features insufficiently preserved to characterize it.

The specimens in Mrs. Gray's collection are all smaller than the holotype, the largest (Pl. XXXII, figs. 3 *a*–3 *c*; G. 25,342) consists of about one and a half whorls, and has a length of 12 mm.; its greatest width = 31 mm.; least width = 27 mm. An unusually high example (Pl. XXXII, fig. 4; G. 25,344) has a length of 15 mm. for three whorls, and width = 21 mm.

Locality.—Balclatchie.

Horizon.—Balclatchie Group (Conglomerate); Lower Ordovician.

LIOSPIRA LENTICULARIS (Sowerby). (Pl. XXXII, figs. 5 *a*–5 *c*.)

Trochus lenticularis Sowerby, 1839, 'Silurian System' p. 642 & pl. xix, fig. 11.
Raphistoma lenticularis Sowerby, 1859, 'Siluria' 3rd ed. p. 549 & pl. x, fig. 10.
Non *Pleurotomaria lenticularis* Conrad, in Emmons, 1842, 'Geology of New York' pt. ii, p. 393, text-figs. 101 & 102.
Non *Pleurotomaria lenticularis* Hall, 1847, 'Palæontology of New York' vol. i, p. 172.

Diagnosis.—Shell disc-like, composed of a few rapidly increasing whorls. Whorls coiled on nearly the same plane, acutely angular at the periphery, flattened convex above, moderately convex below. Band on the outer margin, narrow, slightly grooved, limited on the apical side by a fine thread, a stronger thread on the periphery forming the lower boundary. Lines of growth indistinct, curving back to the band above. Umbilicus wide.

Remarks.—This species is distinguished from members of both *Trochus* and *Raphistoma* by the possession of a sinual band. It somewhat resembles *L. disciformis*, but is smaller, flatter, and has more rapidly increasing whorls. The holotype is only an internal mould with the base embedded in the matrix. A Scottish specimen, though but little better preserved, exhibits the base, the

band at the margin of the whorls, and traces of the lines of growth. *Liospira lenticularis* is much flatter than *L.* (*Helicites*) *qualteriata* Schlotheim, with which species Lindström confounded it.

I have only met with one Scottish example of this species, which I have compared with the holotype, and find it agrees very nearly in character and size.

The holotype is from the Upper Llandovery at Sturedge Hill, Worcester, and is in the Geological Society's Collection in the Museum of Practical Geology, London, No. 6870. Its greatest width = 25 mm.

The Scottish specimen (Pl. XXXII, figs. 5 *a*–5 *c*) has greatest width = 23 mm.; least width = 18 mm.; length = 4 mm. It is in the Hunterian Museum, University of Glasgow, and was presented by Mrs. Gray. No. S 622.

Locality.—Penkill.

Horizon.—Penkill Group; Upper Llandovery.

Genus EOTOMARIA Ulrich, 1897.

EOTOMARIA CONVEXA, sp. nov. (Pl. XXXII, figs. 6 *a* & 6 *b*.)

Diagnosis.—Shell conical, composed of a few rapidly increasing whorls. Whorls subangular near the middle of the body-whorl, smooth, flattened convex above, convex below. Band immediately above the periphery, flat. Lines of growth forming a shallow sinus on the band, curving backward to it above, and forward below. A hardly perceptible ridge exists a short distance below the band. Umbilicus narrow. Aperture subquadrate.

Remarks.—This species is represented by a single internal mould, which is fairly well preserved. It comes nearest to *E. vicina* Ulrich & Scofield (pl. lxix, figs. 18–20), but differs in the whorls being more convex and of greater height above the band.

Holotype (Pl. XXXII, figs. 6 *a* & 6 *b*).—Hunterian Museum, University of Glasgow. Presented by Mrs. Gray. No. S 581.

Dimensions.—Length = 10 mm.; width = 11 mm.

Locality.—Drummuck.

Horizon.—Drummuck Group; Upper Ordovician.

EOTOMARIA THRAIVENSIS, sp. nov. (Pl. XXXII, figs. 7–9.)

Diagnosis.—Shell conical, composed of about six whorls. Whorls subangular, very slightly convex above. Band immediately above the periphery narrow, grooved, and bounded on each side by a thread. Lines of growth curving back to it above and below, with moderate obliquity. Base convex, not much produced, subangular a short distance below the band. Umbilicus narrow and deep. Aperture subquadrate.

Remarks.—There are nine specimens of this form in Mrs.

Gray's Collection, all internal and external moulds. The spire is more elevated than in *Eotomaria convexa*, the band narrower, and the whorls are lower and less convex.

Holotype.—Pl. XXXII, fig. 7. Internal mould, G. 25,411.

Paratypes.—Pl. XXXII, fig. 8 (G. 25,414), aperture of an internal mould; fig. 9 (G. 25,413), wax impression of apical whorls from an external mould.

Dimensions.—Length of holotype = 9 mm.; width = 12 mm. Length of fig. 8 = 10 mm.; width = 11 mm. Length of fig. 9 = 10·5 mm.; width = 12 mm.

Locality.—Thraive Glen.

Horizon.—Drummuck Group (Starfish-Bed); Upper Ordovician.

Eotomaria subplana, sp. nov. (Pl. XXXII, fig. 10.)

Diagnosis.—Shell conical, low, composed of about six whorls. Whorls subangular near the middle, flattened above, convex below. Band of medium width, situated above the periphery, lines of growth curving back to it above with moderate obliquity, and sloping forward below with apparently greater obliquity. Base convex, umbilicus rather narrow. Aperture unknown. Section of whorl subquadrate.

Remarks.—The only example of this shell in Mrs. Gray's Collection is very imperfect, but enough is preserved to warrant us in regarding it as a new form. It is larger than the other two Scottish species, and the whorls are flatter.

Holotype.—Pl. XXXII, fig. 10; G. 25,441.

Dimensions.—The greatest length exhibited = 18 mm.: width = 22 mm.

Locality.—Balclatchie.

Horizon.—Balclatchie Group (Conglomerate); Lower Ordovician.

Genus CLATHROSPIRA Ulrich, 1897.

Clathrospira trochiformis (Portlock). (Pl. XXXII, figs. 11–13.)

Pleurotomaria trochiformis Portlock, 1843, 'Report on the Geology of the County of Londonderry, &c.' p. 14 & pl. xxx, fig. 9.

Diagnosis.—Shell trochoidal, composed of about five whorls. Whorls angular, flattened convexo-concave above, slightly concave or flat below. Band situated on the angle, submedian on the body-whorl, juxta-sutural on the whorls of the spire; almost vertical, of moderate width, slightly grooved, and bounded on each side by a strong thread. Lines of growth strong and clearly defined, forming crescents on the band, running backward to it above, and obliquely forward at first below, then almost vertically, and finally turning back to the umbilical region. The surface of the shell presents a fretted appearance, owing to numerous exceedingly fine lines which cross the lines of growth. Base but little

produced, imperforate, subangular at a short distance below the band. Aperture quadrate, inner lip somewhat thickened, or slightly reflected on the columella.

Remarks.—There are three examples of this species in Mrs. Gray's Collection, all more or less crushed and partly embedded in the matrix, but the surface is generally well preserved. *Clathrospira trochiformis* bears some resemblance to *Pleurotomaria claustrata* Lindström from the Silurian of Gotland, but is more depressed, and the band is on or above, instead of below, the periphery.

Holotype.—This is in the Museum of Practical Geology, London; it is compressed and embedded in the matrix, and came from the Caradocian of Desertcreat (Tyrone). Associated with it is a specimen (No. 35,781) showing the aperture, which is figured here, Pl. XXXII, fig. 11.

The length = 28·5 mm.

The largest of Mrs. Gray's shells has a length of 15 mm. for the four whorls exposed, and a width of 23 mm. (Pl. XXXII, fig. 13; G. 25,384).

Locality.—Ardmillan.

Horizon.—Balclatchie Group; Lower Ordovician.

Genus BEMBEXIA Œhlert, 1887.

BEMBEXIA GLOBOSA, sp. nov. (Pl. XXXV, figs. 8 *a*–8 *c*.)

Diagnosis.—Shell conical, composed of about seven rapidly-increasing angular whorls. Angle a little above the middle of the body-whorl, and considerably below the middle of the earlier whorls, concave above, also immediately below the angle, then convex with a slight subangularity on the base. There is a ridge below the upper suture, and another midway between it and the angle. Band situated on the angle, grooved and bounded by keels. Lines of growth very oblique immediately above and below the band, continuing downwards almost vertically; forming crescents on the band, indicating a moderately deep sinus. Aperture subquadrate, not much produced. Inner lip reflected on the body-whorl. Columella thickened, slightly inclined. No umbilicus.

Remarks.—I refer this species to *Bembexia*, as it seems to accord most nearly with the characteristics of that genus. It must, however, be remarked that the band is not quite so wide as that of the Devonian genotype, *B. larteti* (Munier-Chalmas), which D. & P. Œhlert (1887, p. 24 & pl. ix, fig. 1) describe as having the 'fente large et peu profonde', and which they consider similar to the Silurian *Pleurotomaria biformis* Lindström and *P. hindei* Lindström (1884, pp. 98, 99 & pl. vii, figs. 39–42, pl. xix, figs. 15, 16). Since *B. globosa* also resembles these forms, especially the first-named, it appears advisable to associate it with them; but I regard it as specifically distinct from both, by the character of its ornamentation, as well as by the absence of an umbilicus: in this latter feature it agrees with the genotype.

Holotype.—Pl. XXXV, figs. 8 *a*–8 *c*; G. 25,355. Mrs. Gray's Collection.

Dimensions.—Length = 22 mm.; width = 21 mm. With this are four other specimens from the same locality, one of which is larger, but not so well preserved. It measures 26 mm. in length and 30 mm. in greatest width.

Locality.—Thraive Glen.

Horizon.—Drummuck Group; Upper Ordovician.

Genus LOPHOSPIRA Whitfield, 1886.

Perangulata Section Ulrich, 1897.

Perangulata Subsection Ulrich.

LOPHOSPIRA OBLIQUESTRIATA, sp. nov. (Pl. XXXIII, fig. 8.)

Diagnosis.—Shell of medium size, composed of more than four whorls. Whorls acutely angular near the middle, concave above and below, a strong keel on the angle representing the sinual band, a slighter keel near the suture, and another below, on the body-whorl, about the same distance from the band. Lines of growth sharp and distinct, curving very obliquely backward to the band above, and forward below, making an acute bend on the band itself, indicating a narrow sinus. Base convex, umbilicus small. Aperture imperfectly known.

Remarks.—I have only met with two specimens of this species, both of which are imperfect; the surface of one is, however, extremely well preserved. It bears most resemblance to *L. perangulata* Hall (1847, p. 41 & pl. x, fig. 4), but is larger, and has a distinct keel below the suture which is absent in that species. It differs from *L. obliqua* Ulrich (1897, p. 965 & pl. lxxii, figs. 6–8) in having a more flange-like band and more oblique lines of growth.

Holotype.—The best-preserved specimen (Pl. XXXIII, fig. 8), consisting of one and a half whorls. Length = 16·5 mm.; width = 15 mm. G. 25,346. Mrs. Gray's Collection.

Locality.—Balclatchie.

Horizon.—Balclatchie Group; Lower Ordovician.

LOPHOSPIRA SHALLOCKENSIS, sp. nov. (Pl. XXXIV, fig. 1.)

Diagnosis.—Shell rather large, composed of more than two whorls. Whorls convex, but slightly angular near the middle, with a strong ridge above at the suture. Band submedian, somewhat prominent, narrow, and limited by a groove on each side. Lines of growth coarse at irregular distances apart, with finer ones between, curving obliquely backwards to the band above, and forwards below, and indicating a shallow notch in the outer lip. Base convex, produced. Aperture longer than wide. No umbilicus.

Remarks.—Mrs. Gray's Collection contains only one specimen

of this species, which is crushed and very imperfect, consisting merely of the body and a portion of the penultimate whorl. I should have hesitated to describe it as a new species, were it not that its distinctive characters appear sufficiently preserved to admit of future specimens being identified with it.

Holotype.—Pl. XXXIV, fig. 1; G. 25,348. Mrs. Gray's Collection.

Dimensions.—Length = 34 mm.; width = 22·5 mm.

Locality.—Shallock Mill.

Horizon.—Whitehouse Group; Middle Ordovician.

LOPHOSPIRA WOODLANDI, sp. nov. (Pl. XXXIII, figs. 7 *a* & 7 *b*.)

Diagnosis.—Shell rather large, turreted. Whorls about five, angular above the middle of the body-whorl, and below in the whorls of the spire, excavated above, almost vertical below; a strong ridge exists between the upper suture and the angle, and another ridge between it and the lower suture. Band on the angle prominent, composed of a thick central keel, with a finer one on each side. Lines of growth coarse, curving back to the band above and forward below with a moderate degree of obliquity, crossed and reticulated on the base by strong spiral threads. Base convex, somewhat produced. Aperture imperfectly known.

Remarks.—There are two specimens in Mrs. Gray's Collection, both more or less crushed and imperfect. This species bears some resemblance to *L. turrita* Portlock; but it is bigger, and has a wider spiral angle.

Holotype.—Pl. XXXIII, figs. 7 *a* & 7 *b*; G. 25,388.

Dimensions.—Length = 32 mm.; width = 40 mm.

Paratype.—G. 25,389.

Locality.—Woodland Point.

Horizon.—Saugh Hill Group; Middle Llandovery.

Serrulata Subsection Ulrich, 1897.

LOPHOSPIRA PTERONOIDES, sp. nov. (Pl. XXXIII, figs. 9 *a*–9 *c*.)

Diagnosis.—Shell of medium size, turreted, composed of about six angular whorls. Whorls convexo-concave above, flattish below, base convex. Band submedian on the body-whorl, below the middle of the whorls of the spire, narrow, trilineate, central thread most prominent, surmounted by a flange-like projection. Lines of growth fine and close together, running back to the band above, and forwards immediately below, then passing directly downwards. Ornamentation above the band, consisting of a rounded ridge a little nearer to the suture than to the band; below, of eight keels on the body-whorl, only two being exposed on the penultimate whorl; microscopic threads covering the entire surface. Aperture subovoid.

Remarks.—The single example of this species is much crushed;

it is, however, remarkable for showing a flange-like projection formed over the band similar to that of *Lophospira serrulata* (Salter). This is well preserved on the body-whorl (Pl. XXXIII, figs. 9 *b* & 9 *c*), and vestiges of it are also seen elsewhere. *L. pteronoides* differs from *L. serrulata* in the flange being less strongly serrated, and in the ornamenting keels being more numerous. Prof. R. P. Whitfield mentions a flange as characteristic of several species of the genus, but Dr. Ulrich (1897, p. 970) has only observed it in *L. serrulata*, and he considers that Whitfield may have mistaken different stages in the growth of this species for distinct forms.

Holotype.—Pl. XXXIII, figs. 9 *a*–9 *c*; G. 25,349. Mrs. Gray's Collection.

Dimensions.—Length = 18 mm.; greatest width = 15 mm. The shell is flattened by pressure: thus the width represented is greater than it must originally have been.

Locality.—Woodland Point.

Horizon.—Saugh Hill Group; Middle Llandovery.

Bicincta Section Ulrich, 1897.

? **Holmi** Subsection Ulrich.

Lophospira cancellatula (M'Coy). (Pl. XXXIII, figs. 1 & 2.)

Murchisonia cancellatula M'Coy, 1852, 'British Palæozoic Fossils' p. 292 & pl. i L, figs. 20, 20 *a*.

Diagnosis.—Shell turreted, composed of at least seven whorls. Whorls angular, flattened above and below; angle near the middle of the body-whorl, but much below in the whorls of the spire. Sinual band situated on the angle, composed of a strong central keel with a finer one on each side. Lines of growth sharp, sloping back to the band above, forming a deep sinus on it, and then running forward at first below, and afterwards slightly backward. Surface ornamented by numerous spiral threads reticulating the lines of growth, from four to six of the upper threads being stronger than the others, those on the base varying irregularly in strength. Base convex. Aperture subrhomboidal, imperfectly known.

Remarks.—The holotype is an internal mould, and exhibits only traces of ornamentation; but associated with it is a shell partly embedded in the matrix, which has the surface better preserved; also there are good specimens in Mrs. Gray's Collection from the same locality, some of which are figured here. The manner in which the anterior whorl overlaps and fills in the suture between the preceding whorls is an interesting feature, and causes a complete example to have a very different appearance from an internal mould. Thus, the suture looks as if it were surmounted by a band in the former, while it is deeply excavated in the latter. The umbilicus also is widely open in the mould, and more or less filled in where the test is preserved. This species bears some resemblance to *L. turrita* (Portlock), but is distinguished by its

less exsert whorls and by the strongly-reticulated spiral threads on the upper part of the whorl.

Holotype.—Sedgwick Museum, Cambridge, figured by M'Coy, 'British Palæozoic Fossils' pl. i L, figs. 20 & 20 *a*.

Dimensions.—Length = 26 mm.; width = 23 mm.

Topotype.—Gray Collection. Pl. XXXIII, fig. 1; G. 25,427.

Dimensions.—Length of the specimen illustrated in fig. 1 = 22 mm.; width = 20 mm.

Locality.—Mullock Hill (1). There are six specimens in Mrs. Gray's Collection from this locality, also one (Pl. XXXIII, fig. 2, G. 25,467) from Newlands (2).

Horizon.—(1) Mullock Hill Group; Lower Llandovery. (2) Saugh Hill Group; Middle Llandovery.

LOPHOSPIRA CANCELLATULA, var. TENUISTRIATA nov. (Pl. XXXIII, fig. 3.)

This variety is distinguished from the typical form by having the band formed of four or five nearly equal threads, instead of three with the central one stronger; on some specimens, however, this difference is observable only on the body-whorl. Also, the upper spiral ornamenting threads are not so strong, some of the shells merely having a single thread stronger than the rest about midway between the band and the suture. All the examples are more or less crushed, and it is difficult to ascertain to how great an extent the variation from the typical form is the result of imperfect fossilization and preservation.

Holotype.—The shell figured in Pl. XXXIII, fig. 3, G. 25,392, consisting of four whorls partly embedded in the matrix. Length = 25 mm.; width = about 30 mm.

Locality.—It and five other specimens occurred at Woodland Point (1). Mrs. Gray's Collection.

There is also a small example, consisting of two whorls embedded in the matrix, from Mullock Hill (2), G. 25,425. Another, from the same locality, having about five whorls, appears to be intermediate between the typical form and the variety. A wax impression taken from the external mould of the body-whorl is figured in Pl. XXXIII, fig. 4; G. 25,428. In this the band is prominent like the type, but it is composed of four threads, and the upper spiral ornamentation is not so strong; this, however, may arise partly from bad preservation. The lines of growth are distinct, and indicate a deep sinus.

Horizon.—(1) Saugh Hill Group; Middle Llandovery. (2) Mullock Hill Group; Lower Llandovery.

LOPHOSPIRA THRAIVENSIS, sp. nov. (Pl. XXXIII, figs. 5 & 6.)

Diagnosis.—Shell turreted, low, composed of about five whorls. Whorls angular, convexo-concave above, slightly concave below. Band on the angle, submedian on the body-whorl, low on

the earlier whorls, rather wide, consisting of a strong central keel, with a finer one on each side. Lines of growth coarse and distinct, curving back to the band above and forward at first below, then passing rather obliquely downwards; forming fine crescents on the band. Two very strong spiral threads above, with a finer one between the lowest and the band; a coarse thread below the band, with sometimes another intercalated; on the base numerous spiral threads: all the threads are nodular at the crossing of the lines of growth. Base convex. Aperture subquadrate, inner lip reflected on the columella. Umbilicus open in the mould, covered by the inner lip when the shell is complete.

Remarks.—There are nine specimens in the collection of Mrs. Gray and one in that of the Misses Gray, all in the condition of internal and external moulds. This species has coarser ornamentation and more excavated whorls than *Lophospira cancellatula* M'Coy; its lower form and more elaborate ornamentation distinguish it from *L. turrita* (Portlock) and *L. bellicarinata* Donald, also the whorls are less flat than those of the former.

Holotype.—Pl. XXXIII, fig. 5; G. 25,407; photographed from a wax impression.

Dimensions.—Length = 19 mm.; width = 19·5 mm.

Paratype.—Pl. XXXIII, fig. 6. Collection of the Misses Gray; also taken from a wax impression.

Locality.—Thraive Glen.

Horizon.—Drummuck Group (Starfish-Bed).

Genus MOURLONIA L. G. de Koninck, 1883.

Subgenus PROMOURLONIA, nov.

Diagnosis.—Shell turbinate, composed of a few convex whorls. Band narrow, level with the surface, limited by a thread on each side, on or immediately above the periphery. Sinus short. Outer lip not receding below, being nearly vertical except immediately below the band, where it advances for a very short space. Umbilicus open.

Remarks.—Two species are referable to this subgenus; on both there are very fine spiral threads, and the lines of growth are bifurcated above. *Promourlonia* is distinguished from *Mourlonia* by the form of the outer lip, the shallow sinus, and the absence of an impressed space above the band. It resembles both *Stenoloron* Œhlert and *Gyroma* Œhlert in its low form, convex whorls, open umbilicus, and in the character of the band. It differs from the former in the band being wider and not situated so high on the whorl, in having one or more raised threads on the surface, and in the umbilicus being narrower; from the latter in having no flattened space below the suture and fewer strong raised threads; thus there is no resemblance to *Horiostoma* as in *Gyroma*.

Genotype.—*Promourlonia furcata*, sp. nov.

PROMOURLONIA FURCATA, sp. nov. (Pl. XXXV, figs. 10 *a*–10 *c*.)

Diagnosis.—Shell turbinate. Whorls few, convex, increasing rapidly. Band submedian on the body-whorl, appearing above the suture on the penultimate whorl. Lines of growth fine and closely packed on the band, indicating a shallow sinus; curving backward above, somewhat strong, bifurcate or with plain lines intercalated; curving forward below for a short distance, then running almost direct into the umbilicus, very fine, with stronger lines intercalated on the base. A prominent ridge on the body-whorl, at a distance below the band of approximately twice its width. Aperture imperfectly preserved, inner lip thin, slightly reflected over the umbilicus.

Remarks.—This species is represented by only one specimen in Mrs. Gray's Collection, which is imperfect and partly embedded in the matrix; but the surface of the body-whorl is well preserved. It somewhat resembles *Mourlonia egens* (Barrande)—which Dr. J. Perner, however, does not consider a typical species of the genus,—but it differs in being lower and having a strong ridge on the body-whorl. It also bears a likeness to the more globose forms of *Pleurotomaria æquilatera* Wahlenberg as figured by Lindström (1884, pl. ix, figs. 26–28), but is distinguished by the angularity on the base, the band being higher on the penultimate whorl and of greater width.

Holotype.—Pl. XXXV, figs. 10 *a*–10 *c*; G. 25,360. Mrs. Gray's Collection.

Dimensions.—Length = 10 mm.; width = 15·5 mm.

Locality.—Bargany Pond Burn.

Horizon.—Camregan Group; Llandovery Series.

PROMOURLONIA AMBIGUA, sp. nov. (Pl. XXXV, figs. 9 *a*–9 *c*.)

Diagnosis.—Shell turbinate, short. Whorls about five, convex. Band submedian on the body-whorl, a short distance above the suture on the penultimate whorl. Lines of growth strong and bifurcated above, running backward to the band, indicating a narrow shallow sinus; then curving forward at first below, and afterwards passing almost vertically into the umbilicus. A thread at the suture, and a coarser one about midway between it and the band, another a short distance below the band, and four slighter threads on the base, rendered slightly and irregularly nodular by the lines of growth. Surface covered by exceedingly fine spiral lines. Base convex. Aperture imperfectly known.

Remarks.—This species is represented by two specimens in the collection of Mrs. Gray, and also by another which she presented to the Hunterian Museum, Glasgow University. None of the examples is entire, but the surface is fairly well preserved. *P. ambigua* somewhat resembles young examples of *Pleurotomaria limata* Lindström, but differs in the lower part of the outer lip not receding, also in the margins of the band—so far as known—being less developed.

Holotype.—Pl. XXXV, figs. 9 *a*–9 *c*; G. 25,361.

Dimensions.—Length = 7 mm.; greatest width = 12 mm.

Locality.—Bargany Pond Burn.

Horizon.—Camregan Group; Llandovery Series.

The specimen (S. 582) in the Hunterian Museum is from Penkill. Penkill Group; Llandovery Series.

Genus PHANEROTREMA Fischer, 1885.

PHANEROTREMA M'COYI, nom. nov. (Pl. XXXVI, figs. 1 *a* & 1 *b*.)

Murchisonia simplex M'Coy, 1852, 'British Palæozoic Fossils' pl. i L, fig. 21 (*non* pl. i K, fig. 44).

Diagnosis.—Shell turbinate, composed of more than three whorls. Whorls increasing rapidly, angular considerably above the middle of the body-whorl, and a little below the middle of the whorls of the spire, flat above, and immediately below the angle, base convex. A keel occurs about midway between the angle and the upper suture, and another keel below. Band situated on the angle, grooved, and limited on each side by a strong thread. Lines of growth sloping back to the band above, forming crescents on the band, curving forward immediately below it, continuing downwards almost vertically to the lower keel, and then backwards to the umbilical region. Very narrowly perforated in the mould. Aperture obliquely oblong.

Remarks.—Mrs. Gray's Collection contains a single small example of this species, which is represented by both an external and an internal mould. It is conspecific with the specimen assigned by M'Coy to his species *Murchisonia simplex*. Salter (1873, p. 83) regarded this form as distinct, and I think that there can be no doubt of that being the case, although the holotype of *M. simplex* is merely an internal mould, and thus unsuited for exact comparison. Besides the specimen figured by M'Coy, there is another from the same locality; both are external moulds, and well enough preserved to permit of excellent wax-impressions being made.

Holotype.—'British Palæozoic Fossils' pl. i L, fig. 21. Sedgwick Museum, Cambridge.

Dimensions.—Length of two whorls = 18 mm. The small example (Pl. XXXVI, figs. 1 *a* & 1 *b*) in Mrs. Gray's Collection has only one whorl preserved: its length = 11 mm., and the width = 14 mm. G. 25,432.

Locality.—Mullock Hill.

Horizon.—Mullock Hill Group; Lower Llandovery.

PHANEROTREMA RUGOSA, sp. nov. (Pl. XXXVI, figs. 2–4.)

Diagnosis.—Shell attaining a large size, low, turbinate, composed of about four whorls. Whorls increasing rapidly, flat or slightly inclined above, convex below, angular above the middle of the body-whorl and near the middle of the earlier whorls. A

prominent ridge on the angle represents the slit in the outer lip, bearing coarse, acutely bent lines of growth. Two thick threads above, and numerous threads below, all strongly reticulated by the crossing of the lines of growth curving back to the band above, and also back from it below. No umbilicus. Aperture suborbicular.

Remarks.—There are six examples of this species in Mrs. Gray's Collection and another has been found by the Misses Gray, but none is well preserved. One of the former is considerably larger than the others, and bears some resemblance to *Pleurotomaria labrosa* Hall, as represented in pl. lxvi, fig. 3, 'Palæontology of New York' vol. iii, 1859, from the Lower Helderberg Group; but the relative proportion of the whorls, as well as the ornamentation, differs. *Phanerotrema rugosa* is also distinct from the specimen from Walsall in the Museum of Practical Geology, which Lindström regarded as conspecific with the Gotland form that he referred to *Pleurotomaria labrosa* Hall.

Holotype.—Pl. XXXVI, fig. 2; G. 25,387.

Dimensions.—Length = 62 mm.; width = 72 mm.

Paratypes.—Pl. XXXVI, fig. 4; G. 25,396 & G. 25,397–99; also fig. 3, in the collection of the Misses Gray, Edinburgh.

Locality.—Woodland Point.

Horizon.—Saugh Hill Group; Middle Llandovery.

Genus PLETHOSPIRA Ulrich, 1897.

PLETHOSPIRA (?) CALEDONIENSIS, sp. nov. (Pl. XXXV, figs. 6 *a*, 6 *b*, & 7.)

Diagnosis.—Shell turbinate, composed of more than four whorls. Whorls increasing rapidly, subangular, flat or slightly excavated above and below. Band on the periphery, wide and bounded by keels. A strong ridge a short distance below, and another above, situated nearer the suture than the band. Lines of growth running obliquely back to the band above, and slightly forward below at first, then almost directly downwards; curved on the band itself, indicating a wide and shallow sinus in the outer lip. Base imperforate, convex, and moderately produced. Aperture rounded pentagonal. Columella thickened above.

Remarks.—I have met with five specimens of this species, the biggest of which is merely an internal mould. Another example consisting only of the greater portion of the body-whorl has the surface well preserved; the band on it has each margin formed of two threads close together with a groove between, instead of a single keel—this is probably the result of wear. *P. caledoniensis* has the base less produced than *P. cassina* (Whitfield) the type of the genus, and more nearly resembles *P. semele* (Hall) as figured and described by Dr. Ulrich (p. 1010 & pl. lxx, figs. 8–10), but it is distinguished by its greater spiral angle. He states, however, that he does not consider *P. semele* a very good example

of the genus. *Plethospira caledoniensis* is also somewhat like *Pleurotomaria subrotundata* Portlock (1843, p. 414 & pl. xxx, fig. 8), but differs in having lower whorls, the upper keel farther from the suture, the keel below stronger, and the lines of growth more oblique.

Holotype.—Pl. XXXV, figs. 6*a* & 6*b*; G. 25,351. Mrs. Gray's Collection.

Paratype.—Pl. XXXV, fig. 7; G. 25,350. Mrs. Gray's Collection.

Dimensions.—Length of holotype = 27 mm.; width = 25 mm. This specimen is slightly crushed obliquely.

The paratype, consisting of a single whorl with a broken base, has a length and width of 25 mm.

Locality.—Balclatchie.

Horizon.—Balclatchie Group (Conglomerate); Lower Ordovician.

Genus HORMOTOMA Salter, 1859.

Hormotoma nigra, sp. nov. (Pl. XXXV, fig. 5.)

Diagnosis.—Shell elongated, turreted, composed of more than seven gradually increasing whorls. Whorls convex and smooth. Sinual band submedian, of moderate width, limited on each side by a very slight thread. Lines of growth fine and close, curving backwards to the band above, bending round on it and sweeping forwards below with a considerable degree of obliquity. Base convex, slightly produced. Aperture imperfectly known.

Remarks.—This species, which is represented by a single example, somewhat resembles *Cyrtostropha robusta*, Donald (1902, p. 327 & pl. viii, fig. 4); but the whorls are higher, and no spiral lines are discernible. From *H. gracilis*, Hall (1847, p. 181, and Ulrich & Scofield, 1897, p. 1014 & pl. lxx, figs. 18–36), it is distinguished by the whorls being less prominent in the middle and the sutures less deep.

Holotype.—Pl. XXXV, fig. 5; G. 25,323. Mrs. Gray's Collection.

Dimensions.—Length = 20·5 mm.; width = 8 mm.

Locality.—Shallock Mill.

Horizon.—Whitehouse Group; Middle Ordovician.

Hormotoma (?) nitida, sp. nov. (Pl. XXXIV, fig. 4.)

Diagnosis.—Shell probably elongated. Whorls low, convex, smooth, and slightly adpressed at the suture. Aperture unknown.

Remarks.—Since this species is only represented by a small fragment, consisting of little more than two whorls exhibiting no distinctive structure, it can only be referred to the genus *Hormotoma* with a query. It somewhat resembles *Catozone striatula*, sp. nov. (p. 426); but the spire is apparently more slender, and the whorls are more regularly convex. This latter characteristic also distinguishes it from *Rhabdostropha primitiva*.

Dimensions.—Length = 12 mm.; width = 9·5 mm.; G. 25,302. Mrs. Gray's Collection.

Locality.—Balclatchie.

Horizon.—Balclatchie Group; Lower Ordovician.

Subgenus DONALDIELLA Cossmann, 1903.

[*Goniospira* Donald, 1902.]

DONALDIELLA PERNERI, sp. nov. (Pl. XXXIV, fig. 5.)

Diagnosis.—Shell very elongated, turreted, composed of more than thirteen whorls. Whorls high, convex and smooth. Sinual band situated near or slightly above the middle of the whorls, forming a prominent rounded ridge. Sutures deep. Lines of growth fairly strong, and sweeping very obliquely forward below the band. Body-whorl produced. Aperture elongated oval, imperfectly preserved.

Remarks.—The only specimen known to me is represented by three partly embedded whorls and the impression of ten additional ones. The form is remarkably attenuated, reminiscent of *Hormotoma articulata* Sowerby; but the band is more prominent. The lines of growth are distinct below, but are not clear upon or above the band. Traces of fine spiral lines are discernible on the penultimate whorl. This species bears a great resemblance to *Donaldiella filosa* Donald, although the spiral angle is smaller, the band is rather higher, and there is not the angularity below on the body-whorl. It is also somewhat like *Goniospira (?) gracillima* (Barrande) Perner (1907, p. 125 & pl. xcvi. figs. 45, 46) in its elongated slender spire: it is distinguished, however, by the prominence of the band.

Holotype.—Pl. XXXIV, fig. 5; G. 25,324. Mrs. Gray's Collection.

Dimensions.—Length = 38·5 mm.; that of the three whorls which are intact = 23 mm.; width of the penultimate whorl = 8 mm.

Locality.—Woodland Point.

Horizon.—Saugh Hill Group; Middle Llandovery.

Subgenus CATOZONE Perner, 1907.

CATOZONE STRIATULA, sp. nov. (Pl. XXXIV, fig. 3.)

Diagnosis.—Shell conical, of moderate size, increasing rather rapidly. Whorls slightly convex, somewhat flattened, subangular immediately above the suture. Sutures deep. Band flat, situated below the middle of the penultimate whorl, indistinctly defined by a very fine thread on each side, another down the centre. Lines of growth curving back to the band above, and very obliquely forward below. Upper surface of the whorl covered by numerous fine spiral lines. Aperture subovoid. Base convex, slightly flattened. No umbilicus.

Remarks.—Only one specimen has the characters preserved, another, though probably conspecific, is too much worn for certain identification. The shape and the ornamentation agree with those of *Catozone* Perner (1907, p. 108), except that the band is rather higher than usual.

Three forms from the Girvan district, previously referred with a query to *Turritoma*, evidently belong to this genus: namely, *T. (?) tenuifilosa* Donald (1906, p. 570), *T. (?) polita* Donald and *T. (?) pinguis* Donald (1902, pp. 330, 331). Since the species *T. (?) tenuifilosa* was founded on a single example, it is of interest to record the existence of another from the same locality, in the collection of the Misses Gray, Edinburgh. The examination of a number of specimens from Drummuck and the Starfish-Bed, Thraive Glen, have led me to the conclusion that *Catozone pinguis* is a variety of *C. polita*, some examples from the latter locality being intermediate in character. *C. polita* greatly resembles an unnamed species of *Catozone* represented by Dr. Perner in his pl. iii, fig. 24. *C. striatula* is distinguished from all these species by having the band situated higher.

Holotype.—Pl. XXXIV, fig. 3; G. 25,325. Mrs. Gray's Collection.

Dimensions.—Length = 17·5 mm.; width = 11·5 mm.

Locality.—Balclatchie.

Horizon.—Balclatchie Group; Lower Ordovician.

Genus OMOSPIRA Ulrich, 1897.

When Dr. Ulrich suggested this genus (1897, p. 944), he stated that, although he placed it in the family Raphistomidæ, he was not satisfied with that position for it. Dr. Cossmann (1915, p. 176) considers that it should be regarded as a member of the Murchisoniidæ, on account of its sinual band; and I agree with him in thinking it more akin to members of that family, or else to those of the Pleurotomariidæ.

OMOSPIRA (?) DEPRESSA, sp. nov. (Pl. XXXIV, figs. 2 *a* & 2 *b*.)

Diagnosis.—Shell rather large, turbinate. Whorls more than three, increasing rapidly, subangular, slightly convex above, more convex below. Body-whorl large, produced downwards; angle considerably above the middle, giving a high-shouldered appearance. Aperture subtriangular. Umbilicus apparently closed, with merely a wide depression behind the inner lip.

Remarks.—The single specimen of this species is so imperfect that I have some doubts as to its relationship. The lines of growth are only preserved on a small portion of the base; but there are slight indications of a broad shallow sinus in the outer lip above the angle that are suggestive of *Omospira*, to which genus I provisionally refer it. In form, it somewhat resembles *Scalites* Emmons; but it differs in not having a sharply angular periphery, and in the whorls being less flattened above. The low

spire distinguishes it from all previously-described species of *Omospira*.

Holotype.—Pl. XXXIV, figs. 2 *a* & 2 *b*; G. 25,327. Mrs. Gray's Collection.

Dimensions.—Length=31·5 mm.; greatest width=28 mm.

Locality.—Balclatchie.

Horizon.—Balclatchie Group; Lower Ordovician.

Family **Loxonematidæ** Koken.

Genus LOXONEMA Phillips, 1841.

Subgenus RHABDOSTROPHA Donald, 1905.

RHABDOSTROPHA PRIMITIVA, sp. nov. (Pl. XXXIV, figs. 9–11.)

Diagnosis.—Shell elongated, composed of more than six whorls. Whorls broad, convex, somewhat flattened above, and adpressed at the suture. Lines of growth sigmoidal, sharp and close, acutely bent about the middle of the whorl, crossed by numerous spiral threads and grooves. Base convex, slightly produced. Aperture imperfectly known.

Remarks.—There are three specimens of this species in Mrs. Gray's Collection, all of which have the lines of growth preserved, and one shows the spiral grooves and threads very distinctly. It is distinguished from the Silurian forms *Rhabdostropha grindrodii* Donald and *Rh. pseudofasciata* Donald by its lower whorls.

Holotype.—Pl. XXXIV, fig. 9; G. 25,301. Somewhat flattened by pressure.

Dimensions.—Length=14·75 mm.; width=6·5 mm.

Paratypes.—Pl. XXXIV, figs. 10 & 11; G. 25,303 & G. 25,300.

Locality.—Shallock Mill.

Horizon.—Whitehouse Group; Middle Ordovician.

RHABDOSTROPHA (?) LATISINUATA, sp. nov. (Pl. XXXV, figs. 1 *a* & 1 *b*.)

Diagnosis.—Shell elongated, composed of more than twelve gradually-increasing whorls. Whorls broad, moderately convex, slightly adpressed at the suture. Ornamented by three or four strong threads, with very fine intervening ones. Lines of growth distinct, sigmoidal, widely sinuated. Base convex, rather flattened. Aperture subovoid, imperfectly known. Umbilical region not clearly seen.

Remarks.—The single specimen of this species is distinguished from *Rh. primitiva* by the majority of the spiral lines being so fine as to be hardly discernible without a lens, only three or four being really strong and distinct, and also in the lines of growth being more widely sinuated. Owing to this latter feature, it cannot be regarded as a characteristic member of the subgenus, consequently I only place it there with a query.

Holotype.—Pl. XXXV, figs. 1 *a* & 1 *b*; G. 25,304.

Dimensions.—Length=30 mm.; width=9 mm.
Locality.—Shallock Mill.
Horizon.—Whitehouse Group; Middle Ordovician.

Genus STEPHANOCOSMIA Cossmann, 1895.

Subgenus SPIRŒCUS, nov.

Diagnosis.—Shell elongated, composed of numerous low whorls. Whorls with a strong submedian keel. Lines of growth sigmoidal, passing obliquely over the keel. Aperture ovoid. No umbilicus.

Remarks.—Although this subgenus possesses the sigmoidal lines characteristic of *Loxonema* sensu stricto, it differs in other respects, and its low subangular whorls suggest affinity with members of the genus *Stephanocosmia*. It is distinguished by having a submedian keel, instead of nodes. The spiral ornamentation resembles that of the section *Tyrsœcus* Kittl, but it is not accompanied by defined axial folds, the lines of growth being merely sometimes fasciculated and slightly impressed. From *Angularia* Koken it differs in having an elongated spire, also in the lines of growth being sigmoidal and not forming an angular sinus on the keel.

Genotype.—*Spirœcus girvanensis*, sp. nov. (Pl. XXXIV, fig. 6; G. 25,312).

Range.—Middle and Upper Ordovician.

Spirœcus girvanensis, sp. nov. (Pl. XXXIV, figs. 6–8.)

Diagnosis.—Shell conical, composed of about twelve gradually-increasing whorls. Whorls low, having a keel slightly above the middle, concave above, convex below. Ornamented by numerous fine spiral threads, with a stronger thread or swelling at the suture. Lines of growth sigmoidal, moderately oblique, greatest sinuosity above the keel. Sutures deep. Aperture subovoid, slightly channelled below, outer lip angular at the keel. Columella curved. Base convex, imperforate.

Remarks.—This well-characterized species is one of the most numerous gasteropods in the Ordovician rocks of Girvan. When the submedian keel is worn away, a narrow groove is observed below—this does not appear to be of the nature of a sinus or slit, for the lines of growth pass over it without deviation or break.

Holotype.—Pl. XXXIV, fig. 6; G. 25,312.

Dimensions.—Length=14·75 mm.; width of penultimate whorl=4·5 mm.

Locality.—Drummuck (1).

Paratypes.—Pl. XXXIV, figs. 7 & 8; G. 25,313 and G. 25,314.

Locality.—Starfish-Bed, Thraive Glen (1).

This species also occurs at Shallock Mill (2), where one of the largest specimens was obtained; its length=26 mm., width=8 mm. Mrs. Gray's Collection.

Horizon.—(1) Drummuck Group; Upper Ordovician. (2) Whitehouse Group; Middle Ordovician.

Genus KATOSIRA Koken, 1892.

Subgenus GIRVANIA, nov.

Diagnosis.—Shell slender, turriculated, composed of numerous rather high whorls. Ornamentation consisting of spiral threads, strongest on the lower part of the whorls. Lines of growth slightly sigmoidal. Aperture elongated, ovoid.

Remarks.—This subgenus resembles *Katosira* sensu stricto in its slender form, and in the ornamenting threads being strongest on the base. It is distinguished by having only indistinct irregular folds which are most evident on the anterior whorls, and continue over the base, instead of being absent there.

Genotype.—*Girvania excavata*, sp. nov. (Pl. XXXV, fig. 2.)

GIRVANIA EXCAVATA, sp. nov. (Pl. XXXV, figs. 2 *a*, 2 *b*, 3, & 4.)

Diagnosis.—Shell elongated, composed of more than thirteen gradually-increasing whorls. Whorls concavo-convex, adpressed at the suture. Lines of growth sharp, slightly oblique, and sigmoidal. Ornamented by numerous spiral threads, two or three of which below the suture, as well as those on the lower part of the whorl, are stronger than the others, all reticulated by the lines of growth. Aperture ovoid, much produced. Base convex.

Remarks.—I have met with seven specimens of this species, several of which show the ornamentation and lines of growth distinctly. Worn examples might be confounded with *Spiræcus girvanensis*, but the whorls are higher, the strong submedian keel is absent, and the lines of growth are different.

Holotype.—Pl. XXXV, figs. 2 *a* & 2 *b*; G. 25,321.

Paratype.—Pl. XXXV, fig. 4; G. 25,322.

Mrs. Gray's Collection.

Dimensions.—Length of the former = 16·5 mm.; greatest width = 4·25 mm. The paratype, consisting of six and a half whorls, has a length of 11 mm.; width = 4·25 mm.

Locality.— Shallock Mill.

Horizon.—Whitehouse Group; Middle Ordovician.

Family **Macluriidæ** Woodward.

Genus MACLUREA Emmons, 1842.

MACLURITES Le Sueur, 1818.

Diagnosis.—'Shell discoidal, much depressed, unilocular; spire not elevated, flat; umbilicus very large, with a groove formed by the projection of the preceding whorls, not crenulated.'

Genotype.—*Maclurea magna* Le Sueur.

Remarks.—I have followed the earlier writers, Le Sueur, Hall, Billings, and M'Coy, in describing the members of this genus as sinistral.

MACLUREA SEDGWICKI, nom. nov. (Pl. XXXVII, figs. 1–5.)

Maclurea magna F. M'Coy, 1850, Rep. Brit. Assoc. (Edinburgh) p. 107.
Maclurea sp. J. W. Salter, 1851, 'List of some of the Silurian Fossils of Ayrshire' Q. J. G. S. vol. vii, p. 176 & pl. viii, figs. 7 *a*, 7 *b*.
Maclurea magna F. M'Coy, 1852, 'British Palæozoic Fossils,' p. 300 & pl. i L, figs. 13, 14.
? *Maclurea maccoyi* J. J. Bigsby, 1868, 'Thesaurus Siluricus,' p. 147.
Maclurea logani J. W. Salter, 1873, 'Catalogue of the Cambrian & Silurian Fossils in the Geological Museum of the University of Cambridge' p. 37.
? *Maclurea maccoyi* R. Etheridge, 1888, 'Fossils of the British Islands,' vol. i (Palæozoic) p. 120. ? *M. magna*.

Diagnosis.—Shell slightly convex above, conical below. Whorls about five, increasing gradually, periphery angular, outer sides sloping obliquely downwards. Base ornamented by coarse spiral lines and grooves. Umbilicus deep, narrow, sides steep, subangular at the margin. Aperture ovoid, oblique.

Remarks.—A very young specimen has a groove behind the inner lip, which appears to have been covered by a reflection of that lip; but only a portion of this exists, as it is broken below (Pl. XXXVII, fig. 2); G. 25,365. A similar structure is exhibited by a rather larger example, but it is less well preserved; an internal mould, which is still bigger, merely shows the inner lip slightly curved over an open umbilicus and not adpressed on that region. In the Royal Scottish Museum, Edinburgh, a large conical operculum, A 181 (Pl. XXXVII, fig. 4), is associated with this species, but it was not found actually attached to the shell. It somewhat resembles that of *M. logani* Salter, but is higher. In its height it is like that of *M. peachii* Salter, from which it is, however, distinguished by its much greater size.

M'Coy originally referred this species to *M. magna* Lesueur (1851, p. 107); but it differs in being higher, in having a narrower umbilicus, and in the whorls increasing more rapidly, thus causing the last whorl to be proportionately wider.

Salter figured, but did not describe, this form (1851, pp. 170, 176 & pl. viii, fig. 7); he merely stated that he regarded it as a distinct species, near a new shell from Canada, which he subsequently described under the name of *M. logani* (1859, p. 7). I have compared Salter's as well as other specimens of the species under discussion with examples of *M. logani* in the British Museum (Natural History), and find that the latter has the whorls flatter above, the outer side less oblique, and the umbilicus narrower.

M. sedgwicki is probably conspecific with a form which has been entered in lists of Ordovician fossils as *M. m'coyi* Salter; but I cannot find any certain authority for this. The name first appears in Bigsby's 'Thesaurus Siluricus,' 1868, p. 147, but no reference is given; Etheridge (1888, p. 120) enters it also without authority, and queries its being conspecific with *M. magna*. *M. m'coyi* is recorded in the two Catalogues of Scottish Fossils published in Glasgow, respectively in 1876 and 1901, for the Meetings of the British Association. The late Mr. A. Macconochie, who helped to compile the last Catalogue, stated that he was unable

to find the origin of the name, and only inserted it on account of its being in the lists of the Memoirs of the Geological Survey of Scotland, vol. i, 1899. I have searched Salter's writings, and have neither found a description of it, nor any specimen so named by him.

Holotype.—Pl. i L, fig. 14, 'British Palæozic Fossils.' I have selected this as being the more perfect of the two specimens figured by M'Coy, it is, however, slightly squeezed obliquely (Pl. XXXVII, fig. 1). The other (fig. 13) is larger, but is merely represented in section, and the lower part of the umbilicus is so worn and broken that it appears wider than it must have been originally; the actual narrowness can be seen in the earlier whorls. Sedgwick Museum, Cambridge.

Dimensions.—The holotype has a length of 26 mm., and a greatest width of 52 mm. The cotype has a width of 90 mm.

Locality.—Aldons (1). There are several additional specimens in the same museum, as well as six in the collection of the Misses Gray, Edinburgh, from this locality. Salter's example (G. 19,993) in the British Museum (Natural History) also occurred here. Besides these, the Sedgwick Museum contains two from Bougan, Knockdolian (1); the collection of the Scottish Geological Survey, one from Minuntion (1); and the Hugh Miller Collection in the Royal Scottish Museum, Edinburgh, five from Craighead (1). Two of these last-named show coarse spiral ornamenting threads on the base: one (A 161) is figured in Pl. XXXVII, fig. 5; another (A 157) equals the cotype in size.

In Mrs. Gray's Collection are four smaller specimens from Balclatchie (2); G. 25,365 and G. 25,366 are figured in Pl. XXXVII, figs. 2 & 3.

Horizon.—(1) Stinchar Limestone Group; (2) Balclatchie Group (Conglomerate). Lower Ordovician.

Maclurea salteri, sp. nov. (Pl. XXXVII, figs. 6–9 *c*.)

Diagnosis. Shell attaining a large size, low, flat, or slightly convex above. Whorls about seven, early ones very narrow, the last wide; the test of each succeeding whorl adpressed on the posterior one, and filling in the suture. Periphery rounded, body-whorl but little produced, outer side convex and scarcely oblique. Lines of growth curving slightly backward above, passing over the periphery without deflection, and then running almost directly downwards, crossed by very fine spiral threads. Umbilicus wide, deep, and steep; margin subangular. Aperture ovoid, or somewhat trigonal.

Remarks.—This species is distinguished from *M. sedgwicki* in being lower, in having a broader umbilicus, the outer side nearly vertical, and the body-whorl proportionately wider. This latter feature also separates it from *M. magna* Lesueur and *M. bigsbyi* Hall. The low form and wide body-whorl cause it to resemble somewhat *M. neritoides* Eichwald; but the outer side of that species slopes inward more, and the whorls appear to be fewer in number.

The collection of the Scottish Geological Survey contains the largest number, as well as some of the best-preserved examples; therefore I have selected the holotype and paratypes from it.

Holotype.—Pl. XXXVII, fig. 6 (M 3076 *d*).

Dimensions.—The length = 24 mm.; the greatest width = 48 mm., and the least width = 41 mm.

Paratypes.—Pl. XXXVII, fig. 7 (M 3151 *d*). The length = 28 mm.; the greatest width = 50 mm.

Pl. XXXVII, figs. 9 *a* & 9 *b* (M. 3081 *d*), a smaller shell, has a length of 19 mm.

Associated with these is a specimen of much greater size, but it is not well preserved. Its width = 78 mm.

Locality.—Minuntion (1).

The largest examples, however, are in the Museum of Practical Geology, London: but they are merely internal moulds, and have been too much cleaned up. The biggest (24 *a*) has a greatest width of 86 mm. and a least width of 66 mm.

Locality.—This and another (24 *b*) are from Aldons; while a third (24) is only labelled 'Ayrshire.'

Maclurea salteri is represented by a fairly well-preserved young specimen in Mrs. Gray's Collection, which is figured in Pl. XXXVII, fig. 8 (G. 25,373). Its length = 11 mm.; greatest width = 20 mm. There is also a larger much broken example, showing the characteristic umbilicus. G. 25,369.

Locality.—Balclatchie (2).

Horizon.—(1) Stinchar Limestone Group; (2) Balclatchie Group. Lower Ordovician.

Family **Euomphalidæ** De Koninck.

Genus ECCYLIOMPHALUS Portlock, 1843.

LYTOSPIRA Koken, 1896.

Diagnosis.—'Shell spiral, but with the whorls opened and unconnected; on the side corresponding to the upper surface of Euomphali, ridged or angular, on the lower rounded.'

Remarks.—This description is so brief that it is advisable to give fuller particulars, founded on the results of the examination of several species undoubtedly members of the genus. The ridge represents a sinus indicated by the lines of growth which run backward to it above, acutely forward from it at the side, and then curve slightly backward over the more or less flattened-convex base.

A fresh figure is here given of one of the specimens of *E. bucklandi* (pl. xxx, fig. 10 *b*), regarded by Portlock as the type, as well as a drawing of the oblique lines on the side of that shell (Pl. XXXVIII, figs. 1 *a* & 1 *b*). *E. minor* Portlock (pl. xxx, figs. 11 & 12) appears to be conspecific, and is also refigured, Pl. XXXVIII, fig. 3. It is possible that the shell described and figured by Portlock as *Euomphalus parvus* (p. 411 & pl. xxx, fig. 1) may be an immature

stage of this species, having the whorls more closely coiled, the ridge more convex, and the sinus less deep. The only example, however, is too imperfect for certainty.

The types and associated specimens are in the Museum of Practical Geology, London.

Locality.—Desertcreat (Tyrone).

Horizon.—Caradocian.

ECCYLIOMPHALUS BALCLATCHIENSIS, sp. nov. (Pl. XXXVIII, figs. 4 *a*, 4 *b*, 5 *a*, & 5 *b*.)

Diagnosis.—Shell discoidal. Whorls increasing slowly, high and acutely angular above, outer side flattened and making an angle with the rather convex base. Lines of growth above, turning slightly backward, forming a shallow sinus on the upper angle, curving obliquely forward on the side and gently backward on the base.

Remarks.—There are two specimens of this form in the Collection of the Royal Scottish Museum, Edinburgh, marked *E. bucklandi* Portlock. They are distinguished from that species by the whorls increasing more slowly, being proportionately higher, and having a more acute angle above.

Holotype.—Pl. XXXVIII, figs. 4*a* & 4*b*; No. 2910. This is the larger of the specimens, but it only exhibits the base and a portion of the side.

Paratype.—Pl. XXXVIII, figs. 5 *a* & 5 *b*, No. 2911, is younger, and shows both the base and the upper surface.

Dimensions.—The greatest width of the former = 39 mm., least width = 18 mm. Approximate height of tube = 10 mm. The greatest width of the latter = 27 mm.

Locality.—Balclatchie.

Horizon.—Balclatchie Group; Lower Ordovician.

ECCYLIOMPHALUS SCOTICA M'Coy. (Pl. XXXVIII, figs. 6 *a*, 6 *b*, & 7.)

Eccyliomphalus scotica F. M'Coy, 1852, 'British Palæozoic Fossils' p. 301 & pl. i L, figs. 15, 15 *a*.

Diagnosis.—Shell discoidal. Whorls disconnected, coiled on about the same plane, somewhat flattened above, very convex below; on the upper surface near the margin is a strong ridge, having on the inner side a slight concavity separating it from a minor and more convex ridge. Lines of growth curving back and indicating a sinus on the strong ridge; coarse on the base, and running very slightly backward. Section subtriangular and somewhat rounded.

Remarks.—This form differs from *E. bucklandi* Portlock in the whorls being flattened concavo-convex above and much more convex below. The specimen from Mullock referred to this species by M'Coy is a distinct species.

Holotype.—Pl. XXXVIII, figs. 6 *a* & 6 *b*.

Cotype.—Fig. 7. Sedgwick Museum, Cambridge.

Dimensions.—The greatest width of the former = 46 mm., least width = 34 mm.; section of tube = about 16 × 12 mm.

The greatest width of the latter = 45 mm., least width = 32 mm.; section of tube = about 14 × 12 mm.

Locality.—Knockdolian Quarry.

Horizon.—Stinchar Limestone Group; Lower Ordovician.

ECCYLIOMPHALUS MULLOCKENSIS, sp. nov. (Pl. XXXVII, figs. 10 *a*, 10 *b*, & 10 *c*.)

Diagnosis.—Shell discoidal, forming a more or less circular coil with the whorls detached. Whorls triangular, high, with an elevated ridge at the summit and another a short distance inside; outer side convex; base flattened convex. Lines of growth curving slightly backwards to the angle, and forming a sinus upon it; strong and but little curved on the base.

Remarks.—M'Coy confounded this species with *E. scotica*; it is, however, distinguished by being more closely coiled, and by having high and narrow whorls with a flatter base. The figures are taken from wax impressions, as the shell is only represented by external moulds of the upper and under surface.

Holotype.—Pl. XXXVII, figs. 10 *a*–10 *c*. Sedgwick Museum, Cambridge.

Dimensions.—Greatest width = 26 mm.; least width = 20 mm. Height and width of tube almost equal.

Locality.—Mullock Hill.

Horizon.—Mullock Hill Group; Lower Llandovery.

ECCYLIOMPHALUS (?) MACROMPHALUS (M'Coy). (Pl. XXXVIII, figs. 8–11.)

Maclurea macromphala F. M'Coy, 1852, 'British Palæozoic Fossils' p. 300 & pl. i L, figs. 12, 12 *a*–*b*.

Diagnosis.—Shell discoidal, coiled elliptically, deeply sunk above, flattened below, composed of about five whorls. Whorls increasing rapidly, simply in contact, or with a narrow space between; above flat or slightly convex, sloping inwards; subangular at the outer margin and also at the base, convex between the angles, the posterior part of the body-whorl somewhat produced obliquely below. Aperture subtriangular.

Remarks.—It is difficult to place this form, as the lines of growth are not preserved on any of the known examples. M'Coy referred it to *Maclurea*, and it certainly bears some resemblance to members of that genus, more especially to immature specimens of *M. salteri*, but it may be distinguished by being elliptically coiled, by the whorls not being in such close contact, and the body-whorl oblique, slightly produced below, and proportionately wider. Since all the examples are more or less internal moulds, it is possible that the slight space between the whorls of some may have originally been partly or wholly filled by shelly matter. The shape of the whorls is similar to that of members of *Eccyliomphalus*, therefore I am referring it provisionally to that genus;

but it differs in being more closely coiled than the typical forms of the genus. The species that it most resembles is *Euomphalus triquetrus* Lindström (1884, p. 140 & pl. xiii, figs. 32–35), which is referred by Mr. F. Chapman to his new genus *Liomphalus* (1916, pp. 90, 91, & pl. iv, figs. 32, 33). The figures of the genotype *Liomphalus australis* are, however, too imperfect for a satisfactory comparison, and the whorls appear to increase more slowly than in either of the European species.

Holotype.—Pl. XXXVIII, figs. 8 & 9. Sedgwick Museum, Cambridge.

Dimensions.—Greatest width = 24 mm.; least width = 19 mm.

Locality.—Craighead (1).

A specimen in Mrs. Gray's Collection has the upper surface embedded in the matrix; its greatest width = 25 mm.; least width = 19 mm. (Pl. XXXVIII, fig. 10; G. 25,374).

Locality.—Balclatchie (2).

Horizon.—(1) Stinchar Limestone Group; (2) Balclatchie Group (Conglomerate). Lower Ordovician.

Two smaller examples in the Collection of the Scottish Geological Survey appear to be conspecific. One figured in Pl. XXXVIII, fig. 11, No. 145 IV, is from Kilbucho (Peebles-shire). The other, No. 141 IV, is from Wallace's Cast (Lanarkshire). The horizon of both is stated to be Caradocian.

Genus ECCYLIOPTERUS Remele, 1888.

Section LESUEURILLA Koken, 1898.

'Coquille discoïde, à face supérieure enfoncée et à face inférieure plane ou concave. Le bord du tour qui sépare le côté apical abrupt du côté extérieur, également abrupt, est tranchant. Les stries d'accroissement forment un sinus sur l'arête supérieure du tour (Koken MS.). Type, *Lesueurilla infundibulum* Koken.'

Remarks.—The above description is taken from the work of Dr. Perner (1907, p. 156), to whom Koken had shown his MS. description. Previous, however, to this publication, Koken himself published a note (1898, p. 22), separating the species *Maclurea infundibulum* Koken and *M. helix* (Eichwald) from other forms which he had referred to *Maclurea*, and placing them in this new genus; but he only gives a very brief account of its characteristics, therefore I quote from Dr. Perner, who writes more fully. The latter spells the name *Lesueurella*—I have, however, thought it best to adhere to Koken's form of spelling, as it has priority in publication.

Lesueurilla should most probably be regarded as a section of *Eccyliopterus*, with which genus it has much in common; but it differs in the whorls being coiled in contact from the beginning, the latter part of the body-whorl alone being detached sometimes, and in the upper angle not being produced into a prominent flange.

Dr. Ulrich does not consider these characters of material importance, therefore he includes the closely coiled forms without a produced flange in the genus *Eccyliopterus*. Thus, he regards *Euomphalus marginalis* Eichwald, which is devoid of a flange, and merely has a portion of the body-whorl detached, as a member of that genus; while Koken and Dr. Perner both quote it as a characteristic member of *Lesueurilla*.

Lesueurilla also bears a likeness to the genus *Ophileta* Vanuxem, especially above. I have compared it with specimens in the British Museum (Natural History) referred to *Ophileta compacta* Salter from near Old Church, Baile na Cille, Durness, which have the surface fairly well preserved. The lines of growth run backward to the keel, and form a sinus, and there is also a groove below the keel similar to that in *Lesueurilla*; but the base is flat, the whorls are narrower, and the aperture is not produced downwards.

LESUEURILLA SCOTICA, sp. nov. (Pl. XXXVI, figs. 10–13.)

Diagnosis.—Shell discoidal, spire deeply, base more or less sunk. The whorls number about five, coiled on nearly the same plane, in contact, acutely angular above, subangular below, sloping obliquely inwards to the suture from both angles, outer side slightly convex and nearly vertical. A groove on the inner side, below the upper angle, gives rise to the appearance of a strong thread on the summit. Lines of growth indistinctly preserved, apparently running back to the angle above, forming a sinus upon it and curving slightly forward below. Traces of fine spiral lines ornamenting the surface. Aperture triangular, acutely angular and greatly raised above, less produced and moderately angular below.

Remarks.—There are seven specimens of this form in Mrs. Gray's Collection, which vary slightly in the degree of concavity both above and below. It bears considerable resemblance to *Euomphalus marginalis* Eichwald, and I have compared it with examples of that species from Öland in the British Museum (Natural History); these latter differ in having the anterior part of the body-whorl free, and in the whorls being less angular below. *L. scotica* is somewhat like *Eccyliopterus beloitensis* Ulrich & Scofield; but the aperture is higher, the last whorl narrower, the base more angular, and there is no trace of the upper angle being produced into a high collar. It is distinguished from *L. prima* (Barrande) by having the last whorl narrower, and the angles both above and below nearer the outer margin.

Holotype.—Pl. XXXVI, figs. 10 *a* & 10 *b*; G. 25,378.

Dimensions.—Greatest width = 18 mm., least width = 15 mm., height of aperture = 9 mm., width = 6·5 mm.

Paratypes.—Pl. XXXVI, figs. 11, 12, & 13; G. 25,377, 25,379, & 25,376. The greatest width of the biggest (G. 25,376) = 25 mm. and least width = 22 mm.; height near aperture = 14 mm.

Locality.—Balclatchie.

Horizon.—Balclatchie Group (Conglomerate); Lower Ordovician.

LESUEURILLA BALCLATCHIENSIS, sp. nov. (Pl. XXXVI, figs. 14 *a* & 14 *b*.)

Diagnosis.—Shell discoidal above, the whorls of the spire are on nearly the same level as the body-whorl, the latter increasing somewhat rapidly and being produced downwards. Whorls numbering about four, angular above and below, sloping abruptly inwards, slightly convex exteriorly between the two angles. Umbilicus deep and funnel-shaped. Lines of growth not well preserved, apparently curving back on the outer side to the upper angle, and making a sinus thereon. Aperture forming an oblique and elongated triangle.

Remarks.—The single specimen of this species is merely an internal mould, and is crushed sideways above, which renders the aperture more oblique than it probably was originally. It resembles *L. scotica*, but is distinguished by having the earlier whorls more raised above, the umbilicus deeper, and the aperture more produced downwards. It is, however, impossible to divine how far these differences arise from imperfect preservation. The form appears to have greater affinity with *Lesueurilla* than with *Helicotoma*, as the aperture is more produced below than in the latter genus.

Holotype.—Pl. XXXVI, figs. 14 *a* & 14 *b*; G. 25,375. Mrs. Gray's Collection.

Dimensions.—Length=13 mm.; width=15 mm.

Locality.—Balclatchie.

Horizon.—Balclatchie Group (Conglomerate); Lower Ordovician.

Family **Euomphalopteridæ** Koken.

Genus EUOMPHALOPTERUS Rœmer, 1876.

EUOMPHALOPTERUS ORDOVICUS, sp. nov. (Pl. XXXVI, figs. 5–8.)

Diagnosis.—Shell of medium size, trochoid, composed of five or six whorls. Whorls step-like, subangular, flattened or slightly convex above, flat at the sides; a thread is seen on the periphery, and an angle at the lower suture bearing a prominent overlapping flange adhering to the succeeding whorl. Base smooth, convex, with a slight angularity. Umbilicus widely open. Surface of the whorls and flange fluted. Aperture rounded.

Remarks.—This form is represented by fourteen specimens which occurred in both the Lower and the Upper Ordovician. I cannot discern any features of distinct specific importance in examples from the different horizons; but, since none of the shells are in really good preservation, it is possible that the discovery of others might afford evidence of such characters. Two specimens from the Starfish-Bed (Pl. XXXVI, figs. 7 & 9) exhibit fine wavy lines crossing obliquely the broad flutings of the flange, as well as part of the body-whorl; they appear to form an inner layer between the upper and lower shell-layers, and probably

represent those observed by Lindström on species from Gotland. He considered them to be the result of the filling-up of a sinus in the outer lip; I have, however, been unable to detect any evidence of a sinus in the Scottish examples, for the lines of growth pass over the whorl, and continue on the upper layer of the flange without break: also, where the flange is broken away, there is no internal trace of there having been one.

Euomphalopterus ordovicus somewhat resembles *Pleurotomaria togata* Lindström (1884, p. 119 & pl. xi, figs. 8–13); but the flange is thinner and more produced.

Holotype.—Pl. XXXVI, fig. 5; G. 25,440. The length = 8 mm.; width without the flange = 13 mm., with the flange = 20 mm.

Associated with this are six paratypes, one of which (Pl. XXXVI, fig. 6; G. 25,442) has a length of 8 mm. and a width of 14 mm.

Locality.—Balclatchie (Conglomerate) (1).

There are three specimens from Ardmillan (1): the base of one is shown in fig. 8; G. 25,435. Also two examples are represented from Thraive Glen (Starfish-Bed) (2), Pl. XXXVI, figs. 7 & 9; G. 25,464 & G. 25,463.

All the above are in Mrs. Gray's Collection. There is also an example represented by both external and internal moulds in the Collection of the Misses Gray from Ardmillan (1); and another in the Hunterian Museum, Glasgow University, presented by Mrs. Gray, from Drummuck (2).

Horizon.—(1) Balclatchie Group; Lower Ordovician. (2) Drummuck Group; Upper Ordovician.

The collection of the Geological Survey in the Royal Scottish Museum, Edinburgh, contains a form greatly resembling these, but it is too imperfectly preserved for certain identification. It is from the Caradocian at Wallace's Cast, near Abingdon (Lanarkshire).

Family **Calyptræidæ** Koken.

Genus CLISOSPIRA Billings, 1865.

Clisospira balclatchiensis, sp. nov. (Pl. XXXIII, fig. 11.)

Diagnosis.—Spire elevated, conical. Whorls about four, flattened above, very slightly convex along the outer slope, subangular below. Sutures distinct. Only a fragment of the border is preserved. The base is not exposed. Ornamentation consisting of numerous strong ridges sloping very obliquely backward, and continuing over the border.

Remarks.—This species is most like *C. helmhackeri* (Barrande) from Bande $D_{1\beta}$ (Perner, 1911, p. 265 & text-figure 312); but the whorls are higher and the ornamenting ridges are more numerous and less strong, also no intercalated fine lines are discernible. The length of the shell and the strength of the ornamentation distinguish it from *C. occidentalis* Whitfield

(1882, p. 222 & pl. v, fig. 21) from the Trenton Group of Wisconsin.

Holotype.—Pl. XXXIII, fig. 11; G. 25,364. The only example known to me is in Mrs. Gray's Collection.

Dimensions.—Length = 10·5 mm.; greatest width at the base = 9 mm.

Locality.—Balclatchie.

Horizon.—Balclatchie Group; Lower Ordovician.

CLISOSPIRA RETICULATA, sp. nov. (Pl. XXXIII, figs. 10 *a* & 10 *b*.)

Diagnosis.—Spire low, conical, composed of about four whorls. Whorls moderately convex, slightly flattened above. Ornamentation consisting of raised spiral threads, reticulated by strong undulating lines of growth. Base unknown.

Remarks.—Only one example of this species is known to me; it is, however, represented by both an internal and an external mould. A wax impression taken from the latter consists of four whorls with a portion of the border, and shows the character of the test. Dr. Perner (1911, pp. 262–267 & text-figures 310–314) has observed that sections of some specimens indicate that the earlier whorls were spirally coiled and united so as almost to form a columella; but later on the divisions were reduced to a thin spiral plate, which stops before the completion of the body-whorl. The internal mould of *C. reticulata* has an angularity at the periphery and a deep narrow groove at the suture, which does not reach the aperture. Wax pressed into this groove shows that it represents an internal spiral lamella similar to that described by Dr. Perner; an early whorl also exhibits the columella-like structure.

This species resembles the genotype, *C. curiosa* Billings (1861–65, pp. 186, 420, & text-figures 167, 401), in its reticulated surface, but it has a greater spiral angle, and the whorls are more convex. It is also distinct from the Baltic Ordovician species described by Koken.

Holotype.—Pl. XXXIII, figs. 10 *a* & 10 *b*; G. 25,363.

Dimensions.—Length = 10 mm.; width at the base of the last whorl = 11 mm.; width of the border = 2 mm.

Locality.—Thraive Glen.

Horizon.—Drummuck Group (Starfish-Bed). Upper Ordovician.

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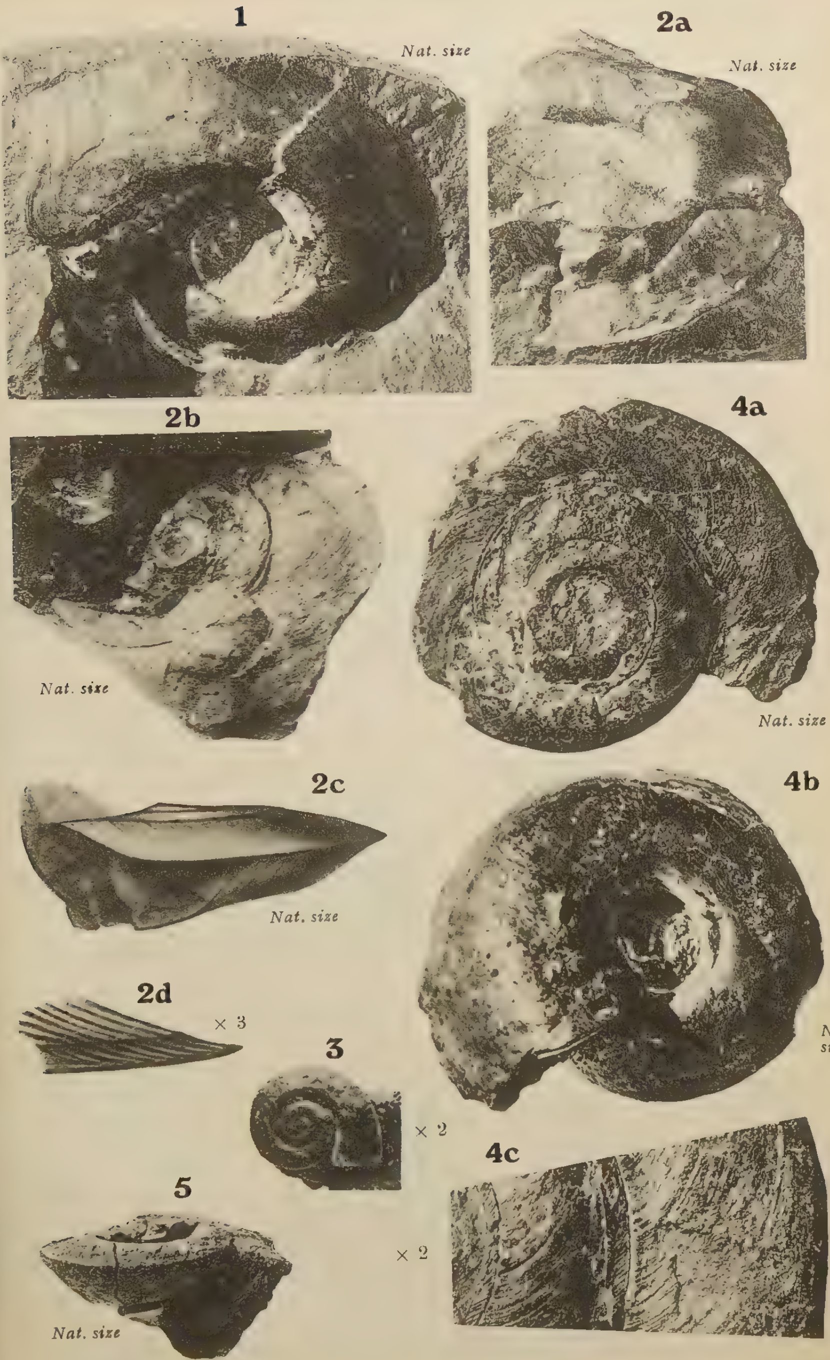

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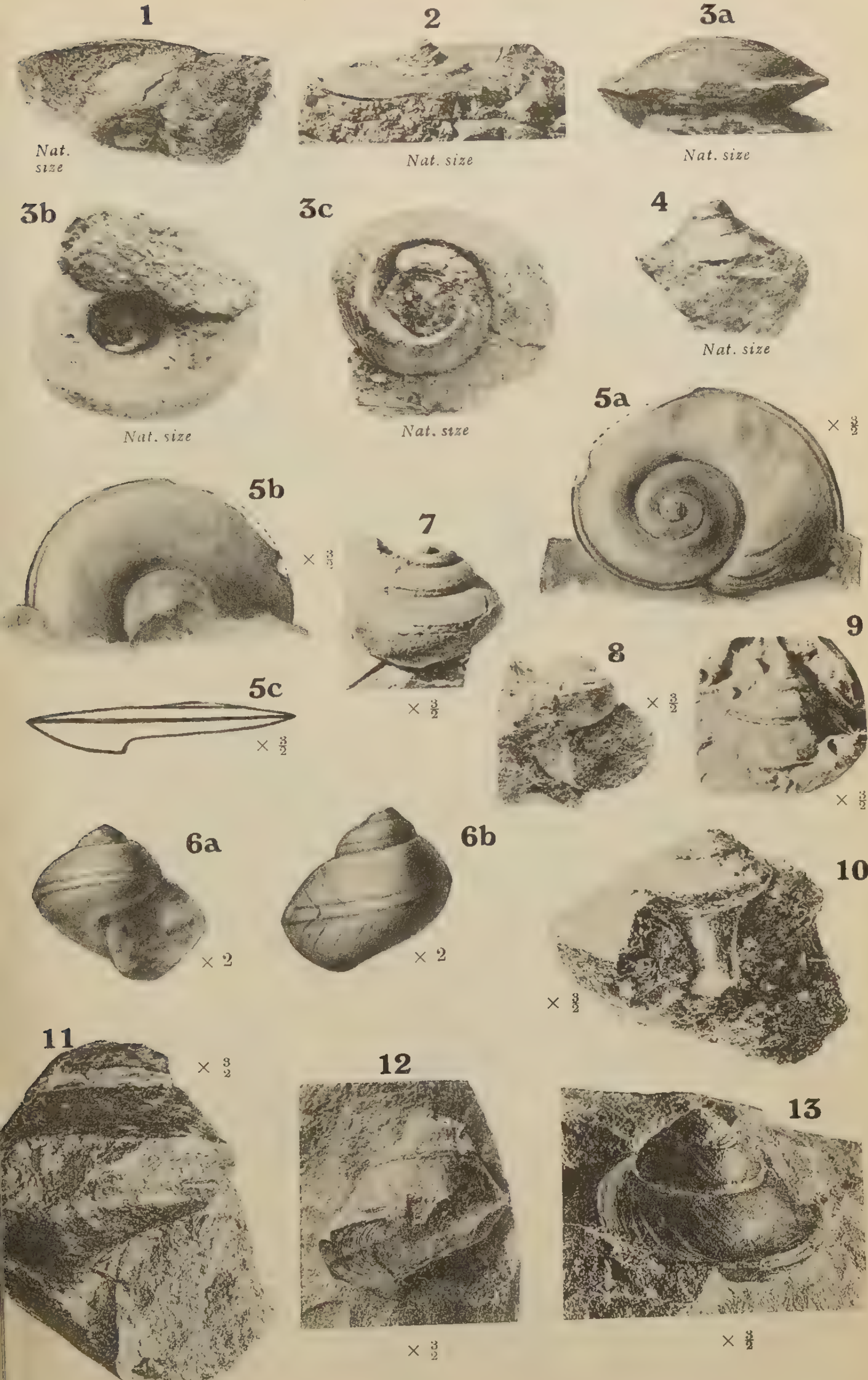
LIOSPIRA.



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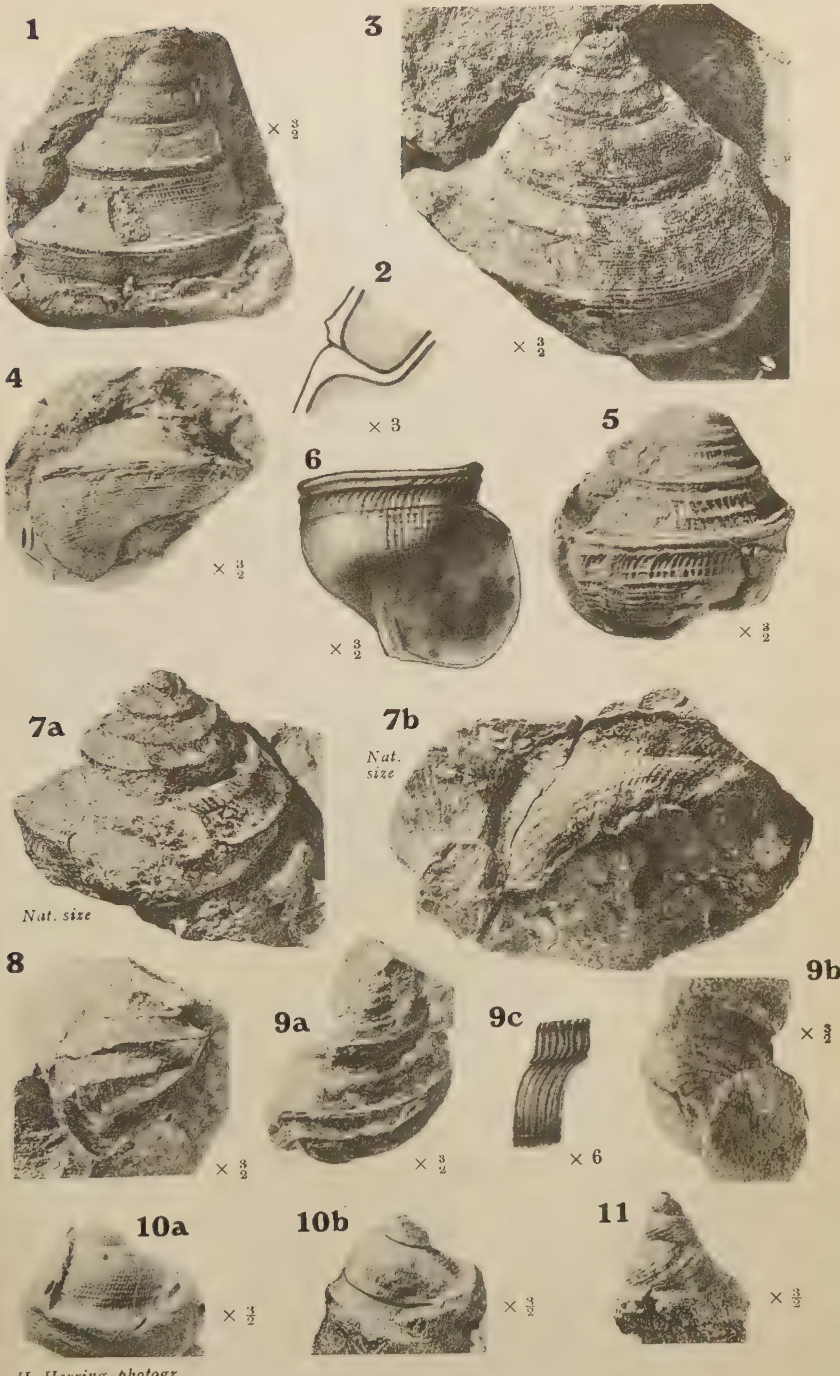
LIOSPIRA, EOTOMARIA, and CLATHROSPIRA.



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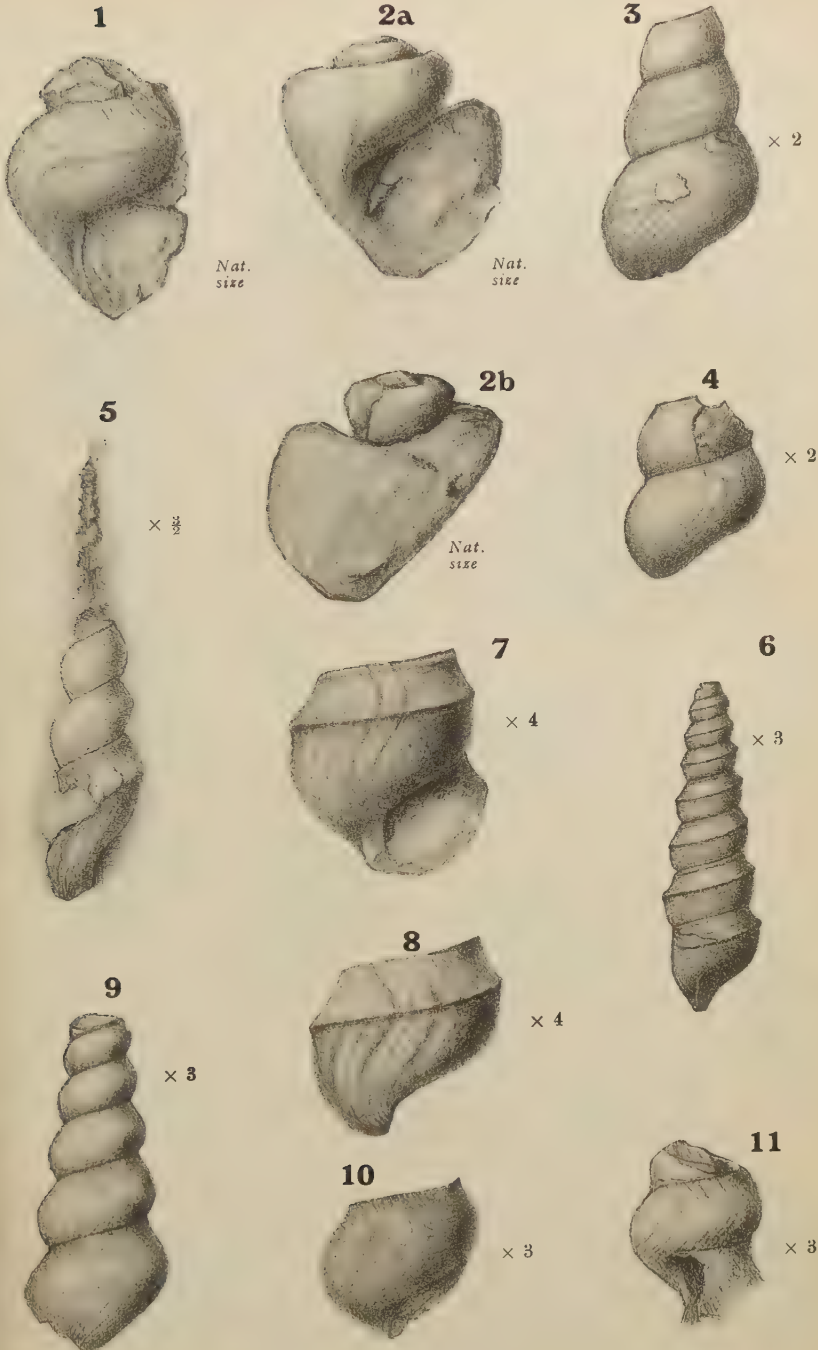
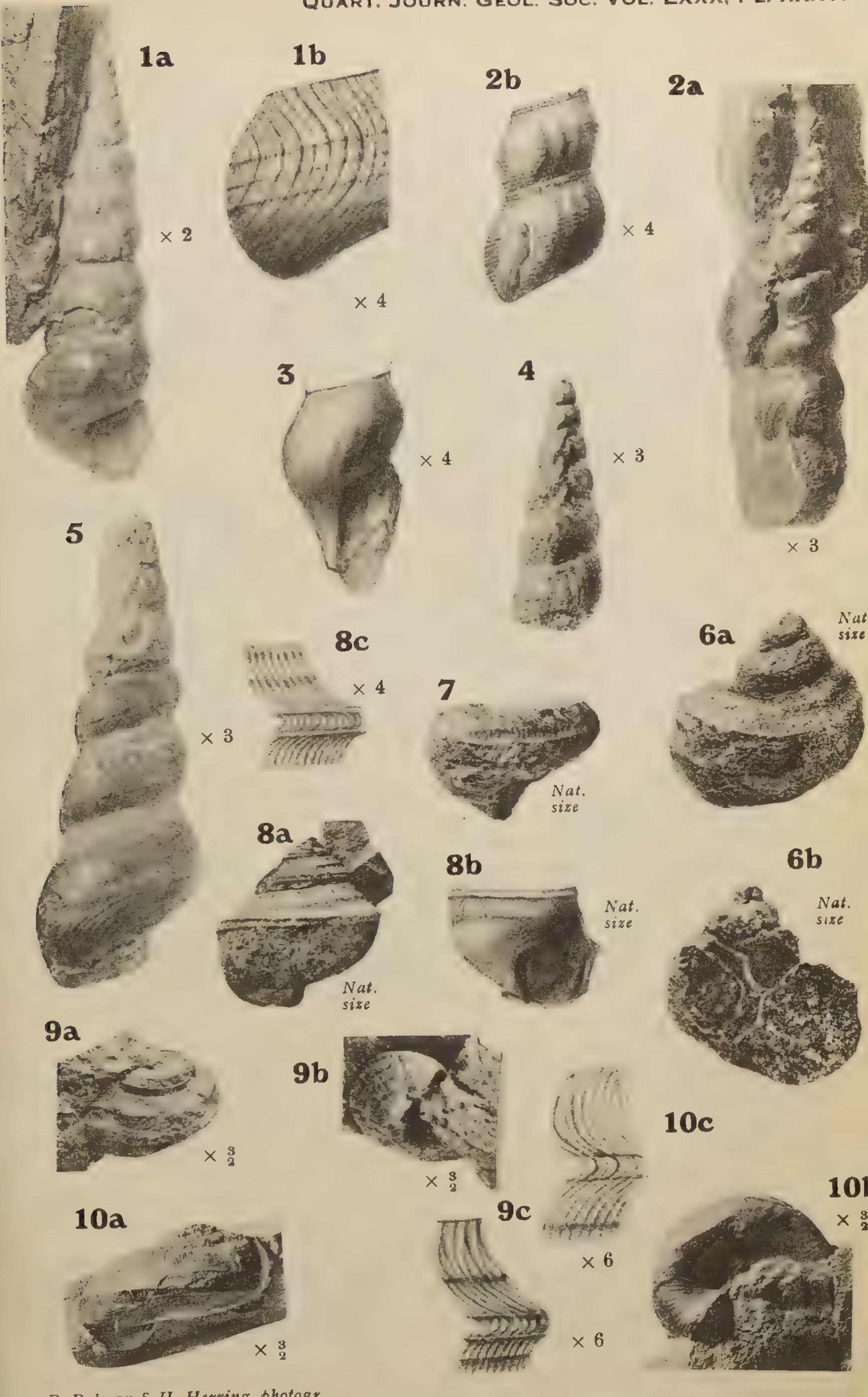
LOPHOSPIRA and CLISOSPIRA.



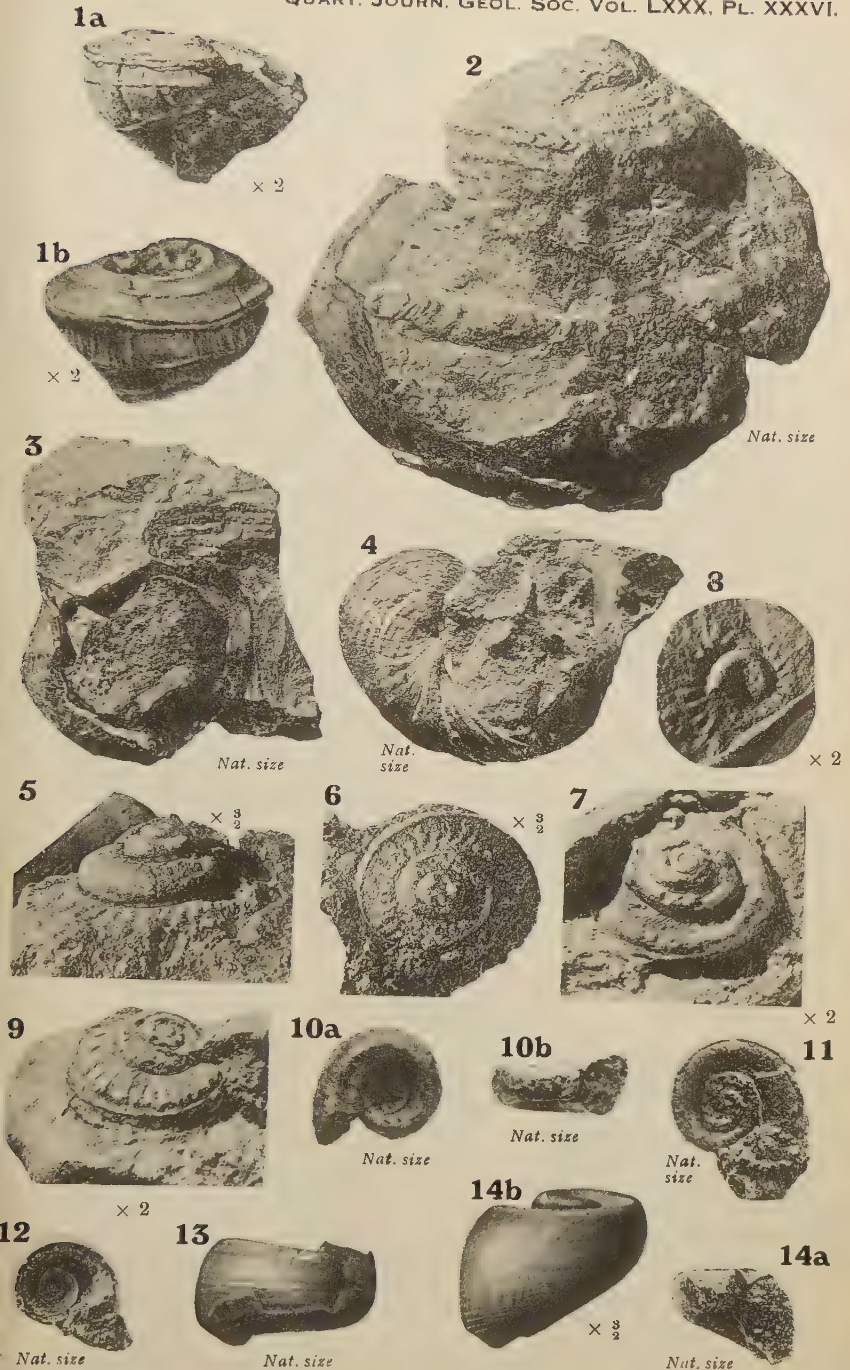
J. Longstaff, del.

PLEUROTOMARIIDÆ and LOXONEMATIDÆ.



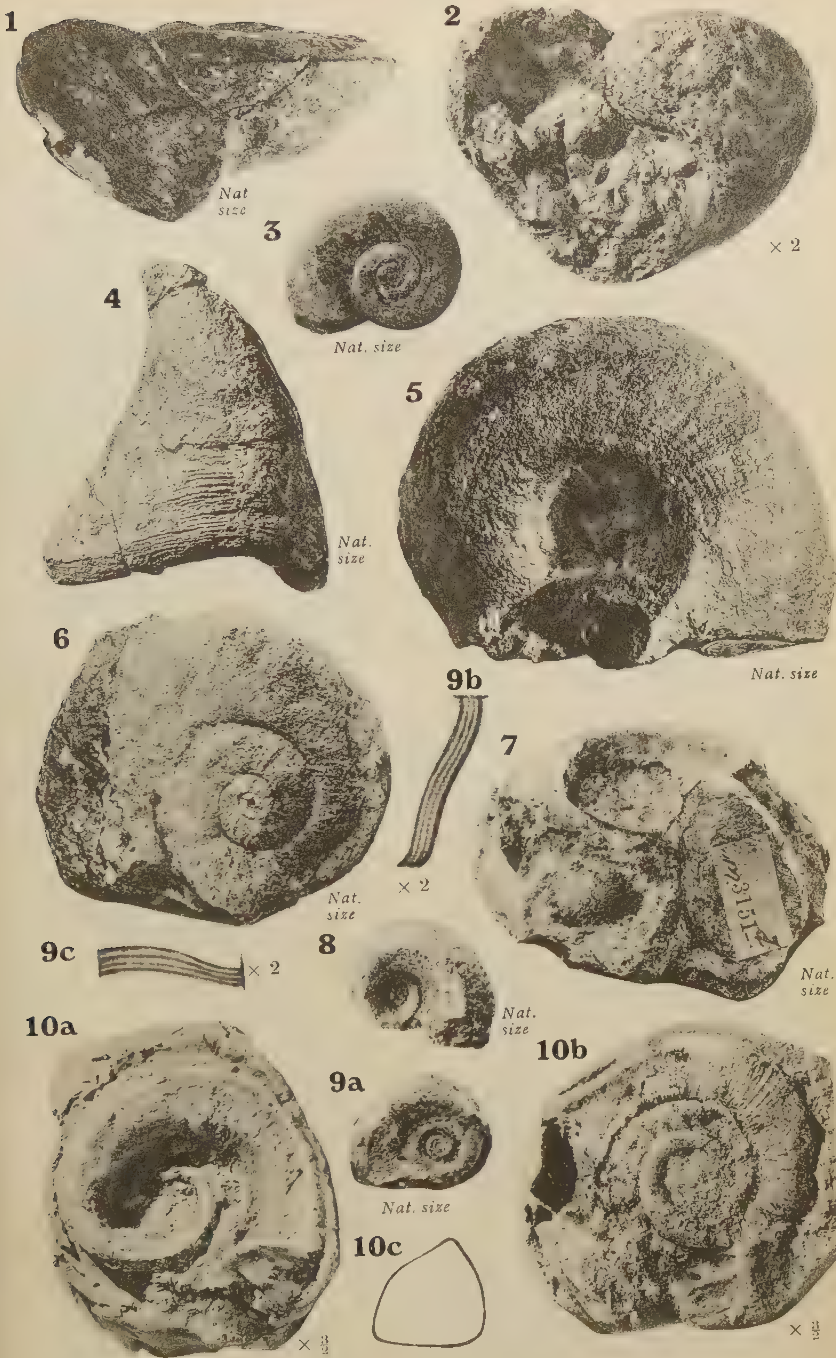
P. Dolman & H. Herring, photogr.
J. Longstaff, del.

PLEUROTOMARIIDÆ and LOXONEMATIDÆ.



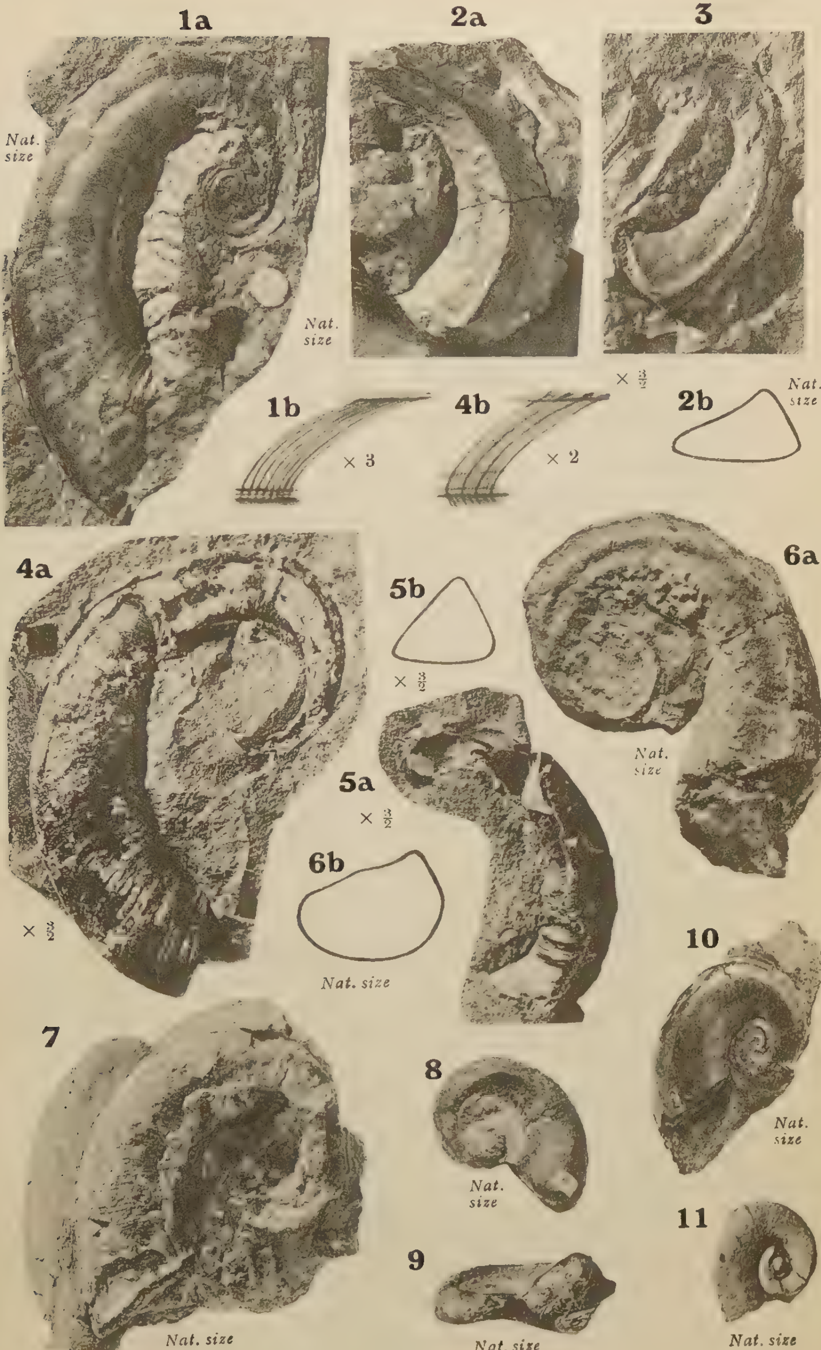
I. Herring, photogr.
. Longstaff, del.

PHANEROTREMA, EUOMPHALOPTERUS, and LESUEURILLA.



H. Herring, photogr.
J. Longstaff, del.

MACLUREA and ECCYLIOMPHALUS.



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EXPLANATION OF PLATES XXXI–XXXVIII.

Plate XXXI.

Fig. 1. *Liospira disciformis*, sp. nov. View of base. Natural size. Dow Hill. Gray Collection, British Museum (Natural History). (See p. 411.)

Figs. 2 *a*–2 *d*. *Liospira disciformis*, sp. nov. Fig. 2 *a*. Holotype. View of base. Fig. 2 *b*. View of upper side. Fig. 2 *c*. Front view. Natural size. Fig. 2 *d*. Portion of band, × 3. Dow Hill. Gray Collection, British Museum (Natural History). (See p. 411.)

Fig. 3. *Liospira disciformis*, sp. nov., juv. View of upper side. × 2. Balclatchie. Gray Collection, British Museum (Natural History).

Figs. 4 *a*–4 *c*. *Liospira striatula* (Salter MS.). Holotype. Fig. 4 *a*. View of upper side. Fig. 4 *b*. View of base. Natural size. Fig. 4 *c*. Portion of body and penultimate whorls, showing structure. × 2. Penwhapple Burn, Girvan. Museum of Practical Geology, London. (See p. 411.)

Fig. 5. *Liospira striatula* (Salter MS.). Front view, showing the filling-in of the umbilicus, below and above, giving the appearance of a solid columella. Natural size. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 411.)

Plate XXXII.

Fig. 1. *Liospira striatula* (Salter MS.). Specimen showing aperture and plug in umbilicus. Natural size. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 411.)

2. *Liospira striatula* (Salter MS.). Another specimen: upper view, with whorls broken away and the solid plug left standing up. Balclatchie. Gray Collection, British Museum (Natural History).

Figs. 3 *a*–3 *c*. *Liospira æqualis* (Salter). Fig. 3 *a*. Back view. Fig. 3 *b*. View of base. Fig. 3 *c*. View of upper side. Natural size. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 412.)

Fig. 4. *Liospira æqualis* (Salter). Shell with elevated spire. Natural size. Balclatchie. Gray Collection, British Museum (Natural History).

Figs. 5 *a*–5 *c*. *Liospira lenticularis* (Sowerby). Fig. 5 *a*. Upper view. Fig. 5 *b*. View of base. Fig. 5 *c*. Outline of back view. × $\frac{3}{2}$. Penkill. Hunterian Museum, University of Glasgow. (See p. 413.)

6 *a* & 6 *b*. *Eotomaria convexa*, sp. nov. Fig. 6 *a*. Holotype. Front view. Fig. 6 *b*. Back view. × 2. Drummuck. Hunterian Museum, University of Glasgow. (See p. 414.)

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8. *Eotomaria thraivensis*, sp. nov. View of aperture. × $\frac{3}{2}$. Thraive Glen (Starfish-Bed). Gray Collection, British Museum (Natural History).

9. *Eotomaria thraivensis*, sp. nov. View of apical whorls from a wax-impression. × $\frac{3}{2}$. Thraive Glen (Starfish-Bed). Gray Collection, British Museum (Natural History).

10. *Eotomaria subplana*, sp. nov. Holotype. × $\frac{3}{2}$. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 415.)

11. *Clathrospira trochiformis* (Portlock). Aperture of a specimen showing a portion of the inner lip. × $\frac{3}{2}$. Desertcreat (Tyrone). Museum of Practical Geology, London. (See p. 415.)

12. *Clathrospira trochiformis* (Portlock). Body-whorl of a specimen showing lines of growth. × $\frac{3}{2}$. Ardmillan. Gray Collection, British Museum (Natural History).

13. *Clathrospira trochiformis* Portlock. Side view. × $\frac{3}{2}$. Ardmillan. Gray Collection, British Museum (Natural History).

Plate XXXIII.

Fig. 1. *Lophospira cancellatula* (M'Coy). Spire showing ornamentation and lines of growth. $\times \frac{3}{2}$. Photograph from a wax impression. Mullock Hill. Gray Collection, British Museum (Natural History). (See p. 419.)

2. *Lophospira cancellatula* (M'Coy). Suture of another specimen. $\times 3$. Newlands. Gray Collection, British Museum (Natural History).

3. *Lophospira cancellatula*, var. *tenuistriata* nov. Shell slightly crushed. $\times \frac{3}{2}$. Woodland Point. Gray Collection, British Museum (Natural History). (See p. 420.)

4. *Lophospira cancellatula* (M'Coy). Back view of the body-whorl of a shell intermediate between the type and the variety. $\times \frac{3}{2}$. Photograph of a wax impression. Mullock Hill. Gray Collection, British Museum (Natural History). (See p. 420.)

5. *Lophospira thraivensis*, sp. nov. Holotype. Back view. $\times \frac{3}{2}$. Photograph of a wax impression. Thraive Glen. Gray Collection, British Museum (Natural History). (See p. 420.)

6. *Lophospira thraivensis*, sp. nov. Aperture of another shell. $\times \frac{3}{2}$. Thraive Glen. Collection of the Misses Gray, Edinburgh.

Figs. 7 *a* & 7 *b*. *Lophospira woodlandi*, sp. nov. Fig. 7 *a*. Holotype. View of spire. Fig. 7 *b*. View of base. Natural size. Woodland Point. Gray Collection, British Museum (Natural History). (See p. 418.)

Fig. 8. *Lophospira obliquestriata*, sp. nov. Holotype. $\times \frac{3}{2}$. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 417.)

Figs. 9 *a*–9 *c*. *Lophospira pteronoides*, sp. nov. Holotype. Fig. 9 *a*. Back view. Fig. 9 *b*. View of aperture. $\times \frac{3}{2}$. Fig. 9 *c*. Flange and portion of whorl. $\times 6$. Specimen flattened by pressure. Woodland Point. Gray Collection, British Museum (Natural History). (See p. 418.)

10 *a* & 10 *b*. *Clisospira reticulata*, sp. nov. Holotype. Fig. 10 *a*. Photograph of a wax impression of the external surface. Fig. 10 *b*. Internal mould, showing grooved sutures. $\times \frac{3}{2}$. Thraive Glen. Gray Collection, British Museum (Natural History). (See p. 440.)

Fig. 11. *Clisospira balclatchiensis*, sp. nov. Holotype. $\times \frac{3}{2}$. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 439.)

Plate XXXIV.

Fig. 1. *Lophospira shallockensis*, sp. nov. Holotype. Front view. Natural size. Shallock Mill. Gray Collection, British Museum (Natural History). (See p. 417.)

Figs. 2 *a* & 2 *b*. *Omospira (?) depressa*, sp. nov. Holotype. Fig. 2 *a*. Front view. Fig. 2 *b*. Back view. Natural size. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 427.)

Fig. 3. *Catozone striatula*, sp. nov. Holotype. $\times 2$. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 426.)

4. *Hormotoma (?) nitida*, sp. nov. Back view. $\times 2$. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 425.)

5. *Donaldiella perneri*, sp. nov. Holotype. $\times \frac{3}{2}$. Woodland Point. Gray Collection, British Museum (Natural History). (See p. 426.)

6. *Spiræcus girvanensis*, sp. nov. Holotype. $\times 3$. Drummuck. Gray Collection, British Museum (Natural History). (See p. 429.)

7. *Spiræcus girvanensis*, sp. nov. View of aperture. $\times 4$. Drummuck. Gray Collection, British Museum (Natural History).

8. *Spiræcus girvanensis*, sp. nov. Back view of body-whorl of another shell. $\times 4$. Drummuck. Gray Collection, British Museum (Natural History).

9. *Rhabdostropha primitiva*, sp. nov. Holotype. $\times 3$. Shallock Mill. Gray Collection, British Museum (Natural History). (See p. 428.)

Fig. 10. *Rhabdostropha primitiva*, sp. nov. Whorl of another specimen showing lines of growth and fine spiral lines. × 3. Shallock Mill. Gray Collection, British Museum (Natural History).

11. *Rhabdostropha primitiva*, sp. nov. Fragment of a shell showing part of the aperture. × 3. Shallock Mill. Gray Collection, British Museum (Natural History). (See p. 428.)

PLATE XXXV.

Figs. 1 *a* & 1 *b*. *Rhabdostropha (?) latisinuata*, sp. nov. Holotype. Fig. 1 *a*. Front view. × 2. Fig. 1 *b*. Portion of the body-whorl showing lines of growth and spiral lines. × 4. Shallock Mill. Gray Collection, British Museum (Natural History). (See p. 428.)

2 *a* & 2 *b*. *Girvania excavata*, sp. nov. Holotype. Fig. 2 *a*. × 3. Fig. 2 *b*. Two whorls showing ornamentation. × 4. Shallock Mill. Gray Collection, British Museum (Natural History). (See p. 430.)

Fig. 3. *Girvania excavata*, sp. nov. Aperture. × 4. Shallock Mill. Gray Collection, British Museum (Natural History).

4. *Girvania excavata*, sp. nov. Apical whorls of another shell. × 3. Shallock Mill. Gray Collection, British Museum (Natural History).

5. *Hormotoma nigra*, sp. nov. Holotype. × 3. Shallock Mill. Gray Collection, British Museum (Natural History). (See p. 425.)

Figs. 6 *a* & 6 *b*. *Plethospira (?) caledoniensis*, sp. nov. Holotype. Fig. 6 *a*. Back view. Fig. 6 *b*. Same shell showing section of body-whorl. Natural size. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 424.)

Fig. 7. *Plethospira (?) caledoniensis*, sp. nov. Another specimen showing lines of growth. Natural size. Balclatchie. Gray Collection, British Museum (Natural History).

Figs. 8 *a*–8 *c*. *Bembexia globosa*, sp. nov. Holotype. Fig. 8 *a*. Back view. Fig. 8 *b*. Aperture. Natural size. Fig. 8 *c*. Band and lines of growth. × 4. Thraive Glen. Gray Collection, British Museum (Natural History). (See p. 416.)

9 *a*–9 *c*. *Promourlonia ambigua*, sp. nov. Holotype. Fig. 9 *a*. Side view. Fig. 9 *b*. View of base. × $\frac{3}{2}$. Fig. 9 *c*. Portion of surface showing band and lines of growth. × 6. Bargany Pond Burn. Gray Collection, British Museum (Natural History). (See p. 422.)

10 *a*–10 *c*. *Promourlonia furcata*, sp. nov. Holotype. Fig. 10 *a*. Back view. Fig. 10 *b*. View of base. × $\frac{3}{2}$. Fig. 10 *c*. Band and lines of growth. × 6. Bargany Pond Burn. Gray Collection, British Museum (Natural History). (See p. 422.)

PLATE XXXVI.

Figs. 1 *a* & 1 *b*. *Phanerotrema m'coyi*, nom. nov. Fig. 1 *a*. Front view with aperture. Fig. 1 *b*. Back view. × 2. Mullock Hill. Gray Collection, British Museum (Natural History). (See p. 423.)

Fig. 2. *Phanerotrema rugosa*, sp. nov. Holotype. Natural size. Woodland Point. Gray Collection, British Museum (Natural History). (See p. 423.)

3. *Phanerotrema rugosa*, sp. nov. Section behind the aperture of another specimen, showing the slit in the outer lip, and impression of a portion of the penultimate whorl. Natural size. Woodland Point. Collection of the Misses Gray, Edinburgh.

4. *Phanerotrema rugosa*, sp. nov. Base of young shell. Natural size. Gray Collection, British Museum (Natural History).

5. *Euomphalopterus ordovicus*, sp. nov. Holotype. × $\frac{3}{2}$. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 438.)

6. *Euomphalopterus ordovicus*, sp. nov. Paratype. × $\frac{3}{2}$. Balclatchie. Gray Collection, British Museum (Natural History).

Fig. 7. *Euomphalopterus ordovicus*, sp. nov. Wax impression of a specimen showing fine lines crossing the flutings. × 2. Thraive Glen (Starfish-Bed). Gray Collection, British Museum (Natural History).

8. *Euomphalopterus ordovicus*, sp. nov. Wax impression of the base of a young shell. × 2. Ardmillan. Gray Collection, British Museum (Natural History).

9. *Euomphalopterus ordovicus*, sp. nov. Wax impression of another specimen, showing fine lines crossing the flutings. × 2. Thraive Glen (Starfish-Bed). Gray Collection, British Museum (Natural History).

Figs. 10 *a* & 10 *b*. *Lesueurilla scotica*, sp. nov. Holotype. Fig. 10 *a*. Base. Fig. 10 *b*. View showing the aperture. Natural size. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 437.)

Fig. 11. *Lesueurilla scotica*, sp. nov. Specimen having the upper surface slightly sunk. Natural size. Balclatchie. Gray Collection, British Museum (Natural History).

12. *Lesueurilla scotica*, sp. nov. Another shell, with the upper surface deeply sunk. Natural size. Balclatchie. Gray Collection, British Museum (Natural History).

13. *Lesueurilla scotica*, sp. nov. Back view of the largest specimen. Natural size. Balclatchie. Gray Collection, British Museum (Natural History).

Figs. 14 *a* & 14 *b*. *Lesueurilla (?) balclatchiensis*, sp. nov. Holotype. Fig. 14 *a*. Front view. Natural size. Fig. 14 *b*. Back view, showing traces of lines of growth. × $\frac{3}{2}$. Shell somewhat squeezed obliquely. Balclatchie. Gray Collection, British Museum (Natural History). (See p. 438.)

Plate XXXVII.

Fig. 1. *Maclurea sedgwicki*, nom. nov. Holotype. Natural size. Aldons. Sedgwick Museum, Cambridge. (See p. 431.)

2. *Maclurea sedgwicki*, nom. nov. Aperture of young specimen showing the inner lip thickened and covering the umbilical region. × 2. Balclatchie. Gray Collection, British Museum (Natural History).

3. *Maclurea sedgwicki*, nom. nov. Upper view of another young shell. Natural size. Balclatchie. Gray Collection, British Museum (Natural History).

4. *Maclurea sedgwicki (?)*. Operculum. Natural size. Craighead. Hugh Miller Collection, Royal Scottish Museum, Edinburgh.

5. *Maclurea sedgwicki*, nom. nov. Base showing spiral threads and grooves. Natural size. Craighead. Hugh Miller Collection, Royal Scottish Museum, Edinburgh.

6. *Maclurea salteri*, sp. nov. Holotype. Upper view. Natural size. Minuntion. Collection of the Scottish Geological Survey, Edinburgh. (See p. 432.)

7. *Maclurea salteri*, sp. nov. Paratype. View of base. Natural size. Minuntion. Collection of the Scottish Geological Survey, Edinburgh.

8. *Maclurea salteri*, sp. nov. View of the base of a young specimen. Natural size. Balclatchie. Gray Collection, British Museum (Natural History).

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10 *a*–10 *c*. *Eccyliomphalus mullockensis*, sp. nov. Holotype. Fig. 10 *a*. Wax impression of the upper side. Fig. 10 *b*. Wax impression of base. Fig. 10 *c*. Approximate form of section. × $\frac{3}{2}$. Mullock Hill. Sedgwick Museum, Cambridge. (See p. 435.)

Plate XXXVIII.

Figs. 1 *a* & 1 *b*. *Eccyliomphalus bucklandi* Portlock. Fig. 1 *a*. Holotype. Base. Natural size. Fig. 1 *b*. Lines of growth at the side. × 3. Desertcreat (Tyrone). Museum of Practical Geology, London. (See p. 433.)

Figs. 2 *a* & 2 *b*. *Eccyliomphalus bucklandi* Portlock. Fig. 2 *a*. Upper view, exhibiting keel and lines of growth. Fig. 2 *b*. Approximate form of section. Natural size. Desertcreat (Tyrone). Museum of Practical Geology, London.

Fig. 3. *Eccyliomphalus minor* Portlock. Upper view. × $\frac{3}{2}$. Desertcreat (Tyrone). Museum of Practical Geology, London. (See p. 433.)

Figs. 4 *a* & 4 *b*. *Eccyliomphalus balclatchiensis*, sp. nov. Holotype. Fig. 4 *a*. Base. × $\frac{3}{2}$. Fig. 4 *b*. Lines of growth at the side. × 2. Balclatchie. Royal Scottish Museum, Edinburgh. (See p. 434.)

5 *a* & 5 *b*. *Eccyliomphalus balclatchiensis*, sp. nov. Fig. 5 *a*. Upper view of a smaller specimen. Fig. 5 *b*. Approximate form of section of whorl. × $\frac{3}{2}$. Balclatchie. Royal Scottish Museum, Edinburgh.

6 *a* & 6 *b*. *Eccyliomphalus scotica* M'Coy. Holotype. Fig. 6 *a*. Upper view. Fig. 6 *b*. Approximate form of section. Natural size. Knockdolian Quarry. Sedgwick Museum, Cambridge. (See p. 434.)

Fig. 7. *Eccyliomphalus scotica* M'Coy. Base of another shell. Natural size. Knockdolian Quarry. Sedgwick Museum, Cambridge.

Figs. 8 & 9. *Eccyliomphalus (?) macromphalus* (M'Coy). Holotype. Fig. 8. Upper view. Fig. 9. View of aperture. Natural size. Craighead. Sedgwick Museum, Cambridge. (See p. 435.)

Fig. 10. *Eccyliomphalus (?) macromphalus* (M'Coy). View of base. Natural size. Balclatchie. Gray Collection, British Museum (Natural History).

11. *Eccyliomphalus (?) macromphalus* (M'Coy). View of the base of another specimen. Natural size. Kilbucho. Collection of the Scottish Geological Survey, Edinburgh.

18. *The* Geological Structure *of the* Clevedon–Portishead Area (Somerset). By Prof. Sidney Hugh Reynolds, M.A., Sc.D., F.G.S., and Edward Greenly, D.Sc., F.G.S. (Read January 9th, 1924.)

[Plate XXXIX—Maps.]

Contents.

I. Introduction.

The area described in the following paper is, in the main, a prominent ridge some 4 miles long, forming the extreme north-western portion of Somerset and stretching from Portishead in the north-east to Clevedon in the south-west (Pl. XXXIX, fig. 1). It is separated from the Clifton–Clevedon ridge by the Gordano valley; but, as one proceeds south-westwards, the two ridges are seen to approach and eventually come together at Clevedon.

The main part of the ridge is geologically very simple, consisting of Old Red Sandstone overlain by the Carboniferous Limestone Series dipping south-eastwards; but at each end the structure becomes very complicated and difficult of interpretation. Owing to this fact, it has been thought desirable to describe the main part of the ridge first.

The district was mapped by Sanders on the scale of 4 inches to the mile, and the Geological Survey for the 1-inch map made but slight alteration in his lines. Little has been written, except about the Portishead end of the ridge. This, however, was described in considerable detail by Prof. C. Lloyd Morgan,[1] and, as his paper deals fully with the earlier work, it will not be necessary to repeat the references to this subject. Arthur Vaughan's[2] work on the palæontological sequence in the Carboniferous Limestone of the Bristol area led him to determine the horizon of the rocks at the chief exposures throughout the district, but he did not attempt any general explanation of the geological structure. Some account of the chief exposures will be found in the Geological Excursion Handbook for the district by one of us (S. H. R.).

[1] 'Contributions to the Geology of the Avon Basin: IV—On the Geology of Portishead' Proc. Bristol Nat. Soc. n. s. vol. v (1885–88) pp. 17–30.
[2] Q. J. G. S. vol. lxi (1905) pp. 228–30.

II. The Portishead–Clevedon Ridge northwards from Dial Hill, Clevedon. (S. H. R.)

In the following pages the succession is described with only sufficient detail to make the account of the structure comprehensible.

(*a*) From Dial Hill, Clevedon, to Nightingale Valley, Weston-in-Gordano.

Throughout this tract, which has a length of about 3 miles, the geological structure is very simple. The area is a ridge of Old Red Sandstone and Carboniferous rocks striking north-eastwards, and bounded on both seaward and landward sides by the Triassic conglomerate. Tongues of this conglomerate extend up the valleys, and isolated patches occur near Walton Castle. Throughout this area the Palæozoic rocks dip south-eastwards at angles varying from 30° to 60°. The Old Red Sandstone, which forms a tract of high ground, covers the largest part of the ridge, the width of its outcrop increasing from only a few yards near Clevedon Pier to two-thirds of a mile north of Nightingale Valley. The *Cleistopora* Beds form, as a rule, a grassy depression, the *Zaphrentis* and *Syringothyris* Beds a second tract of high ground. The *Zaphrentis* Beds and the *Caninia* Oolite are generally well-wooded, while the *laminosa* dolomite (which is rarely exposed) is more frequently under cultivation.

The best sections are

(1) In the neighbourhood of Walton Castle, from Castle Farm to Holly Lane. The upper part of K_2, β, and the lower part of Z are seen immediately east of Castle Farm, while there are exposures of C_1 (*laminosa* dolomite) in Holly Lane and quarries in C_1 (*Caninia* Oolite) at the bottom of the lane.

(2) At Walton-in-Gordano there is a fine section ranging from β to Z_2. The lower beds are seen in Plumley's Quarry, the upper beds in the roadside quarry at Walton and in the crags overlooking the road.

Several small dip-faults shift the strata, the southernmost of these extending from Ladye Bay to Holly Lane. A second affects the outcrop of the K and Z beds north of Walton-in-Gordano, while a third occurs in Nightingale Valley.

(*b*) The Nightingale Valley and Weston Big Wood Exposures.

A fairly good section ranging from the Bryozoa-Bed (horizon α) to C_2 (*Caninia* Dolomite) is seen here. A small quarry near the road east-north-east of Manor Farm exposes the Bryozoa-Bed and the lower part of K_1. The whole of the *Zaphrentis* Beds, from β to γ, is fairly well seen in exposures by the side of the road traversing the wood. The old quarry near the bottom of the road affords a fine section of the whole of the *Caninia* Oolite, while the top of the *laminosa* dolomite and the base of the *Caninia* Dolomite (a horizon not, as a rule, exposed in the Clevedon–Portishead area) are also seen. All these rocks dip south-eastwards at a

moderate angle; but, if we pass on to the Weston Big Wood quarries half a mile to the east, they are found to be opened in Z_2 and γ, lying vertical or sometimes slightly overfolded.

As regards the explanation of this reappearance of the Z beds, it is clearly due to the rocks being folded into a syncline (see figs. 1 & 2, pp. 450–51). Owing to the wooded character of the ground, it is very difficult to trace the outcrops of the several bands, although it is possible to do so in the case of the *Caninia* Oolite.

(*c*) The Fore Hill Exposures.

The puzzling arrangement of the rocks at Fore Hill and in the adjacent lanes (fig. 1) has been fully described by Prof. C. Lloyd Morgan. In the lower part of the lane south of Fore Hill (St. Mary's Lane) dolomitized crinoidal limestone (β or Z_1) with a low south-eastward dip is seen near Greenfield Farm. Farther up, in the neighbourhood of Wetland's Lane, the Palæozoic rocks are hidden by the Triassic conglomerate. Still higher up, near Capenore Court, Old Red Sandstone is well exposed. At the top of the lane, near the point where it bends eastwards, *Cleistopora* Beds are seen, red limestone (perhaps attributable to the Bryozoa-Bed) being fairly well exposed on both sides of the road.

If we pass now to the lane north of Fore Hill, the Bryozoa-Bed is found exposed at the very top, and a little lower down greatly disturbed reddish shale with bands of sandy limestone, all representing the K_m beds, occur. Slightly lower down, vertical Old Red Sandstone is seen. In both these lanes, then, sections of the base of the Carboniferous and top of the Old Red Sandstone are seen, the rocks lying almost vertically and being considerably disturbed. The rocks are exactly on the strike of the highly inclined strata of Weston Big Wood Quarry, and are clearly affected by a continuation of the same sharp synclinal fold. But, while at Weston Big Wood nothing is seen below Z_2, at Fore Hill the fold brings the lowest K beds and Old Red Sandstone to the surface. This is doubtless due to a south-westward pitch of the axis of the fold.

The limestone mass of Fore Hill remains for consideration (see fig. 3, p. 451). It consists of β and Z_1, and the upper strata are noteworthy for the large amount of chert that they contain. They dip at about 20° south-eastwards, and all observers have agreed that their position can only be explained by faulting. Prof. Lloyd Morgan considered that the Fore Hill mass was brought by a normal fault with a low hade 'from the limestone mass which, ere denudation removed it, occupied its normal position over what is now West Hill.' In view, however, of the evidence of thrust-faulting which the district affords, a simpler explanation would seem to be that the Fore Hill mass is analogous to that described by one of us (E. G.) at Dial Hill, Clevedon, and is thrust forward from the south-east. The limestone exposed in St. Mary's Lane near Greenfield Farm is clearly part of the same mass, and it is probable that a patch of limestone with silicified crinoids on the hillside west of Fore Hill is also a thrust mass.

Fig. 1.

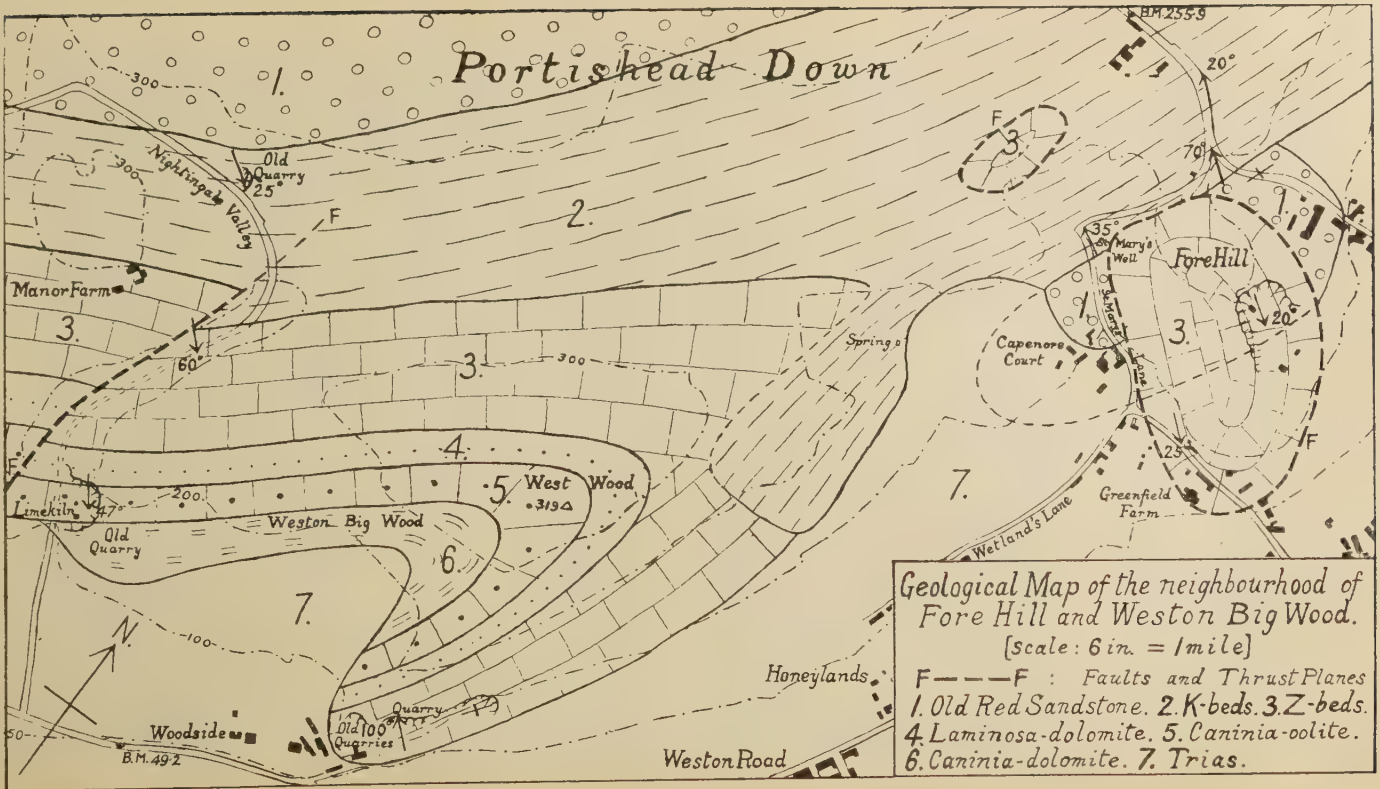
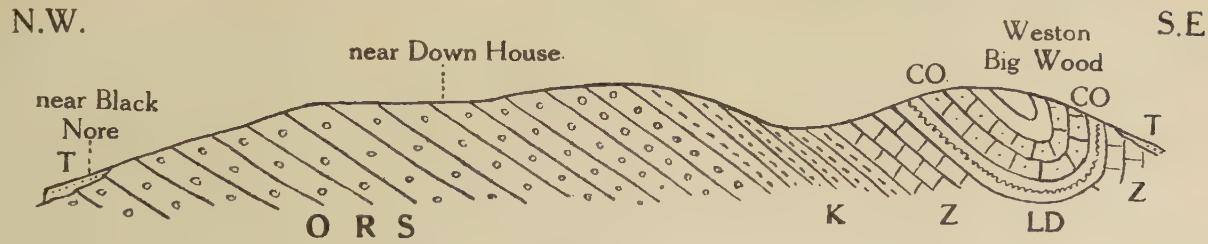
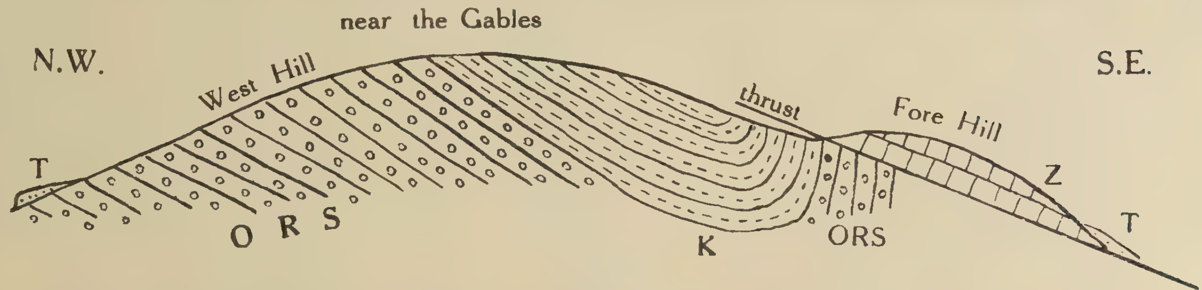

Portishead Down
Old Quarry
25°
Nightingale Valley
Manor Farm
60°
Limekiln
47°
Old Quarry
Weston Big Wood
West Wood
319
200
300
100
50
Woodside
B.M. 49·2
B.M. 255·9
Old Quarries
Quarry
Weston Road
Honeylands
Spring
Capenore Court
St Mary's Well
St Mary's Lane
Fore Hill
Greenfield Farm
Wetland's Lane
35°
70°
20°
25°
N.
1.
2.
3.
4.
5.
6.
7.
F
Geological Map of the neighbourhood of Fore Hill and Weston Big Wood.
[scale: 6 in. = 1 mile]
F———F : Faults and Thrust Planes
1. Old Red Sandstone. 2. K-beds. 3. Z-beds.
4. Laminosa-dolomite. 5. Caninia-oolite.
6. Caninia-dolomite. 7. Trias.

Fig. 2.—*Section from Black Nore Point to Weston Big Wood (Section I in Pl. XXXIX, fig. 1).*



[Scales, horizontal: 4 inches = 1 mile; vertical: 1 inch = 400 feet.]

Fig. 3.—*Section through West Hill and Fore Hill (Section II in Pl. XXXIX, fig. 1).*



[Scales, horizontal: 6 inches = 1 mile; vertical: 1 inch = 400 feet.]

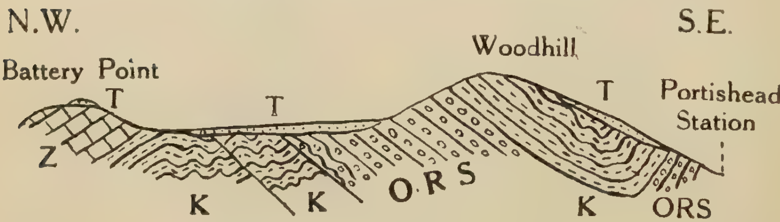
O.R.S. = Old Red Sandstone. K = *Cleistopora* Beds. Z = *Zaphrentis* Beds. CO = *Caninia* Oolite. LD = *Laminosa* dolomite. T = Trias.

(*d*) Exposures in the Neighbourhood of Woodhill.

After being concealed for a space by the overstep of the Trias, the Palæozoic rocks reappear with the same strike at Woodhill (Pl. XXXIX, fig. 2 & text-fig. 4), which, as was recognized by previous observers, is clearly a detached portion of the main ridge. The rocks forming the north-western limb of the fold are seen in several old quarries, the Old Red Sandstone being well exposed in the grounds of Fircliff, while the Bryozoa-Bed (α) is seen in the grounds of 'The Gnoll.'

The rocks forming the trough of the fold are seen in a series of small abandoned quarries in the fields south-west of Royal Terrace. The southern one is in K_1 beds dipping at 18° south-eastwards, and containing the normal fauna; the other quarries are mainly in the Bryozoa-Bed (α), considerably disturbed. The south-eastern limb of the fold is seen in the old overgrown quarry opposite Portishead Station. The rocks here, although coloured as Lower

Fig. 4.—*Section from Battery Point to Portishead Station (Section III in Pl. XXXIX, fig. 2.)*



[Scales, horizontal: 6 inches = 1 mile; vertical, greatly exaggerated.]
O.R.S. = Old Red Sandstone. K = *Cleistopora* Beds. Z = *Zaphrentis* Beds. T = Trias.

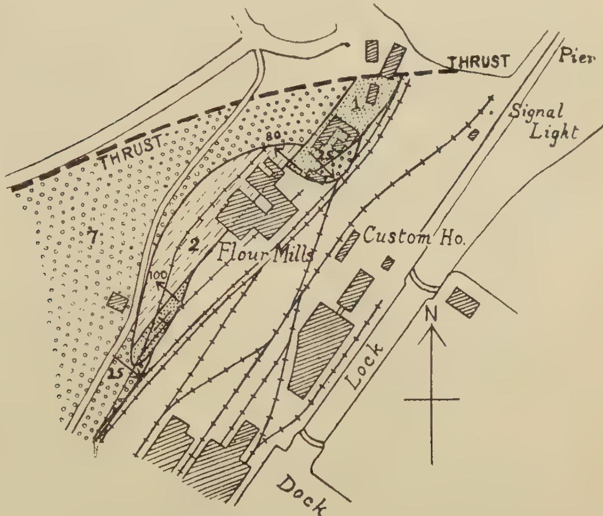
Limestone Shale in Prof. Lloyd Morgan's map, are clearly Old Red Sandstone, the dip of which at the top of the bank is 65° west-north-westwards, while lower down the rocks are practically vertical. The south-eastern limb of the fold is again seen in the old quarry behind the factory near Portishead Pier Station (figs. 5 & 6, pp. 453, 454). At the northern end the Triassic conglomerate rests upon beds affording a passage from the Old Red Sandstone to the Carboniferous, and the exposure is especially interesting from the fact that these strata are not exposed elsewhere in the neighbourhood of Portishead, being hidden by alluvium in the Woodhill Bay Section. The Old Red Sandstone passes up into red calcareous sandy beds and impure limestones, succeeded by the Bryozoa-Bed, which forms the rear wall of the main part of the quarry. At the southern end the Old Red Sandstone overlain by Trias is again exposed. While at the northern end of the quarry the rocks have the normal but very high dip of 80° west-north-westwards, farther

south an apparent dip of 80° east-south-eastwards may be noted: that is, the rocks are slightly overfolded, and really dip at 100° west-north-westwards.

III. The Eastwood Ridge. (S. H. R.) [See Pl. XXXIX, fig. 2, & text-figs. 4–6, pp. 452–54.]

Near the northern end of Woodhill Bay the Bryozoa Bed (α) is well exposed in a low cliff, and is brought by a reversed fault over the upper K_2 beds, which are well seen immediately to the north thrown into a series of five small anticlines and synclines.

Fig. 5.—*Sketch-map of the neighbourhood of Portishead Pier Station.*



[Scale: 12 inches = 1 mile, or 1 : 5280.]

1 = Old Red Sandstone. 2 = *Cleistopora* Beds (K). 7 = Trias.

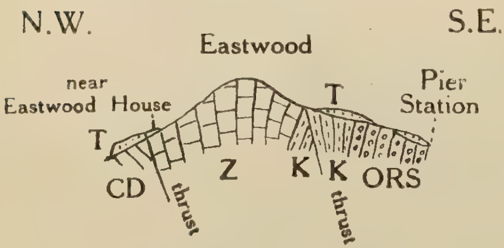
A second section of the disturbed beds in the neighbourhood of this thrust-fault is seen in the shallow cutting at the northern end of the Esplanade, and a third at the northern end of the new road encircling the 'Marine Lake.' The rocks are greatly folded and disturbed in both the sections, which are almost entirely in the Bryozoa-Bed. In addition to the thrust-fault bringing the Bryozoa-Bed over K_2, it is clear from the dip in the rocks of the road-section that the Old Red Sandstone is thrust over the lower K beds (see fig. 4, p. 452).

We may now return to the foreshore section. An interval without exposures separates the disturbed K_2 beds from Battery Point, formed by horizon β. Z_1 succeeds β, and these beds

extend eastwards below a tongue of Trias for about 300 yards, until they disappear, and the Trias forms the cliff as far as a point a short distance east of the house called 'Eastwood.' Here Palæozoic rocks, but in this case Pennant Sandstone, not Carboniferous Limestone, emerge from beneath the Trias, and extend with a northward dip as far as the neighbourhood of the Pier. Three small patches of Pennant Sandstone appear through the Trias on the foreshore, west of the main outcrop.

The prominent wooded ridge of Eastwood (fig. 6), rising steeply to a height of about 200 feet, consists of Carboniferous Limestone, and seems (although exposures are very bad) to be composed throughout of Z beds. Except in a little old quarry near the south-eastern margin of the ridge, where the dip is about 40° north-westwards, the rocks are everywhere vertical or even slightly overfolded to the north.

Fig. 6.—*Section from Portishead Pier Station to Eastwood House (Section IV in Pl. XXXIX, fig. 2).*



[Length = about 300 yards.]

O.R.S. = Old Red Sandstone.
K = *Cleistopora* Beds.
Z = *Zaphrentis* Beds.
CD (should be CM) = Coal Measures.
T = Trias.

The observations recorded above show that the northern margin of the area here described, from Battery Point to the Pier, consists of Carboniferous Limestone (Z beds) fringed on the northern side by a strip of Pennant Sandstone, the junction between the two rocks being concealed by the Trias. Below the Pier Hotel, however, it is clearly seen that the Carboniferous Limestone is thrust over the Pennant Sandstone, the limestone in the neighbourhood of the fault being very much shattered. It is probable that, as is indicated in the map (Pl. XXXIX, fig. 2), this thrust is a continuation of the northernmost of the two that traverse the rocks south of Battery Point, and which there brings the Bryozoa-Bed (α) over K_2. The overthrust Carboniferous Limestone mentioned above, although clearly a continuation of the mass forming Eastwood, is reduced to a band only about 40 yards wide, being cut off on the south by a second fracture, which brings it against the Old Red Sandstone of the Pier Station. This fault continues westwards along the southern margin of Eastwood, and it is probable that, as is suggested in the map, it is a continuation of the southernmost of the two overthrusts south of Battery Point.

IV. Summary of the Tectonics of the Portishead Area. (S. H. R.).

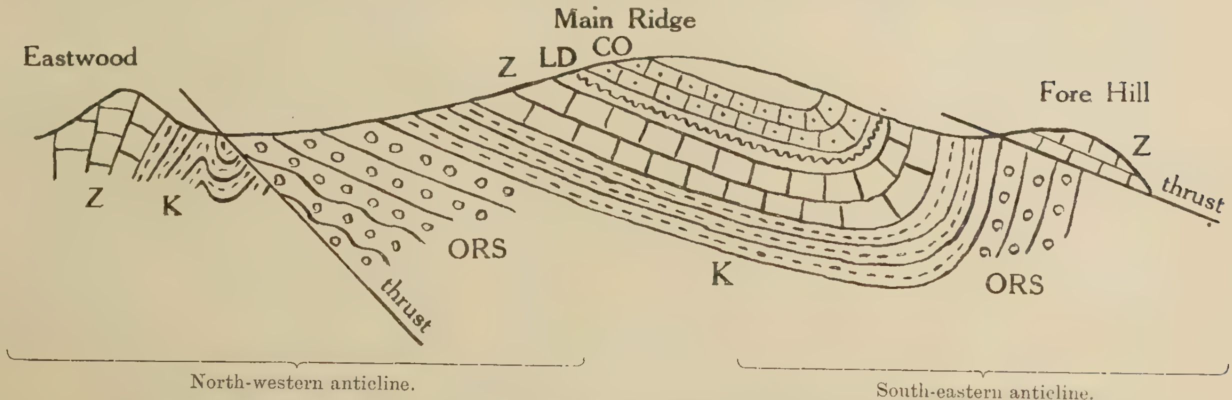
The main Clevedon–Portishead ridge is formed by the north-western limb of a synclinal fold which extends the whole way from Clevedon to Woodhill, Portishead. While the direction of dip remains very uniform, the amount varies much, but is never greater than 60°. The south-eastern limb of the syncline is not seen in the south-western part of the ridge, being first met with in the Weston Big Wood quarry (see fig. 2, p. 451). The exposures in the lanes at Fore Hill, at Portishead Station, and at the Pier Station belong to this limb. The dip of the rocks is everywhere very much higher than in the north-western limb. Thus, in the Weston Big Wood quarry, the dip varies from about 80° to 100°. In the Fore Hill lanes the rocks are much disturbed, and the dips very high. In the Old Red Sandstone quarry at Portishead Station the dip is very high, and in part of the quarry vertical; while the small quarries on Woodhill afford evidence of considerable disturbance. Lastly, at the Pier Station, the dip of the Old Red Sandstone and the K_m beds is very high, and in part of the quarry the rocks are overfolded.

While in the south-western part of the area the rocks forming the trough of the syncline are *Syringothyris* Beds, farther north-east nothing is seen above K_1. An explanation of this may be found by assuming a south-westward pitch of the axis of the fold.

The south-eastern limb of this syncline forms at the same time the north-western limb of an anticline, the arch of which is broken through by a thrust that brings a fragment of the south-eastern limb (the Fore Hill mass) over the north-western limb (see fig. 3, p. 451).

The Eastwood ridge, with its east-and-west strike, remains for consideration. The main part of it is formed of Carboniferous Limestone (Z) which at the western end (Battery Point) has a northward dip of 55°, while throughout the main part of the ridge the rocks are nearly vertical or even slightly overfolded northwards (see fig. 6, p. 454). At the western end there is clear evidence of thrust-faulting from the south, the Bryozoa-Bed being thrust over K_2 and the Old Red Sandstone over the Bryozoa-Bed (see fig. 4, p. 452). It is clear also that the relation between the disturbed K beds south of Royal Terrace, Woodhill, with their general south-eastward dip at a moderate angle, and the Z beds of the old quarry in Eastwood west of Royal Terrace, where the rocks are vertical and strike east and west, must be a faulted one. Near Portishead Pier Station there must certainly be a fault, between the Old Red Sandstone exposed near the platform and at the entrance to the old quarry, and the Carboniferous Limestone seen on the foreshore a few yards away to the north.

Fig. 7.—*Diagrammatic section showing the suggested relationship of the Portishead rocks.*



[O.R.S.=Old Red Sandstone. K=*Cleistopora* Beds. Z=*Zaphrentis* Beds. LD=*Laminosa* dolomite. CO=*Caninia* Oolite.]

The details mentioned above can be understood if the Eastwood ridge is regarded (fig. 7, p. 456) as the terminal portion of the northern limb of an anticline, over or against which the southern limb has been thrust along the fault-line between Battery Point and the Pier Station. The whole Portishead area would then represent two converging anticlinal folds, each of which has its arch broken through by a thrust from the south-east. The junction between the strip of Pennant Sandstone bordering the northern shore and the limestone of Eastwood is also faulted, the limestone being seen below the Beach Hotel to be thrust over the Pennant Sandstone.

V. The Clevedon Area. (E. G.) [Pl. XXXIX, fig. 3.]

(*a*) The Convergence of the Ridges.

The Palæozoic rocks crop out on two distinct lines of strike, which have given rise to two ridges, each about 270 feet in height, one running westwards from Bristol, the other south-westwards from Portishead: the Trias-floored hollow between them being known as the Vale of Gordano. These two ridges converge at Clevedon, their limestones coming together on the high platform east of Dial Hill.

The Palæozoic succession is complete on the north-western ridge from the Old Red Sandstone to the *Caninia* Oolite (the *Caninia* Dolomite being reached near Hillside Lodge); but on the southern ridge, although the *Caninia* Oolite is again reached, the Old Red Sandstone, the K beds, and the base of the Z beds are missing. Moreover, along the curving junction from the 'Court Hill' to the Hill Road, in less than three-quarters of a mile, the Z beds dip, first off Coal Measures, then off the *Caninia* Oolite, then off Coal Measures again, and finally off the *Caninia* Oolite once more. Further, on the southern side of the line the horizon is not constant, changing from Z_2 to the upper part of Z_1 as we pass south-westwards. The width of the Coal-Measure outcrop, too, is reduced (without rise of dip) from 990 yards to nothing in a distance of only 590 yards. Plainly, the convergence is a rupture, but what is the nature of that rupture? That it is not a normal fault is at once suggested by its curvatures, while the dips on both ridges (varying from 30° to 40°, commonly about 40°) are in the same generally southward direction.

(*b*) The Sections at East Clevedon Gap (fig. 8, p. 458).

Now, where the line of junction between the Coal Measures (Pennant Sandstone) and the limestones crosses a huge gap, 240 feet deep, in the southern ridge, which may be called 'East Clevedon Gap,' it curves back southwards as much as 170 yards. On the wooded western crags of the Gap (known locally as Strawberry

Fig. 8.—*Section along the western side of East Clevedon Gap, on the scale of 10 inches to the mile.*

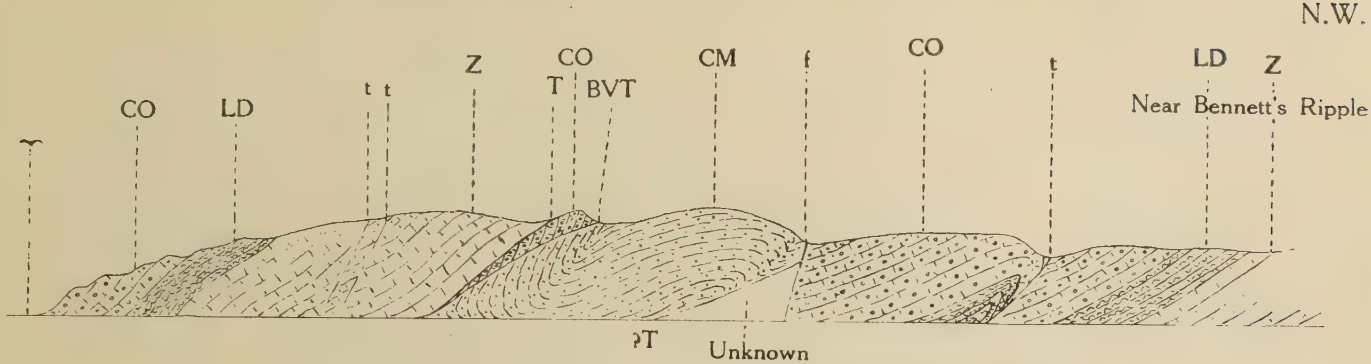
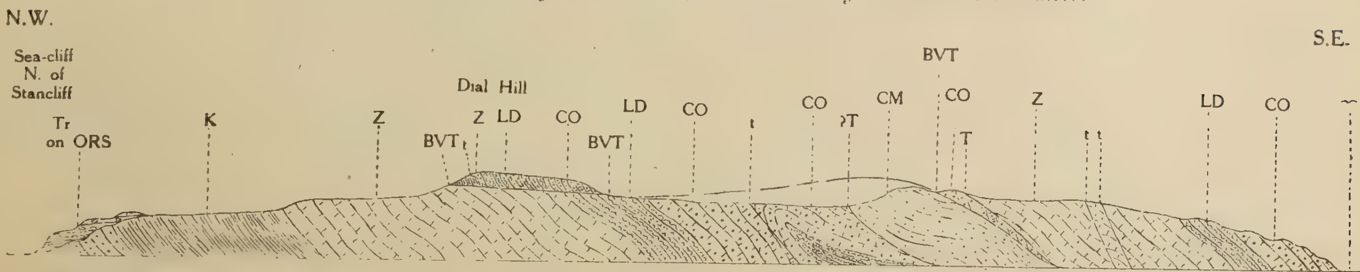


Fig. 9.—*Section through Dial Hill, on the scale of 8 inches to the mile.*



O.R.S. = Old Red Sandstone.
CM = Coal-Measure Sandstone.
K = *Cleistopora* Beds.
Tr = Trias.
f = Fault.
Z = *Zaphrentis* Beds.
⌒ = Alluvium.
BVT = Bella Vista Thrust-plane.
LD = *Laminosa* dolomite.
T, T = Major thrusts.
CO = *Caninia* Oolite.
t, t = Minor thrusts.

Hill and Bella Vista), the *Caninia* Oolite forms a rugged vertical escarpment, the base of which, running down through the woods, has curved back southwards 50 yards where it is crossed by the upper pathway, so that for 50 yards, walking upon Coal Measures, we look vertically up to the mass of *Caninia* Oolite. Fragments of Coal-Measure sandstone occur on the steep slope at the foot of the oolite escarpment. Manifestly, this mass of *Caninia* Oolite is resting upon Coal Measures and on a plane inclined at quite a moderate angle. The actual junction does not seem to be exposed at present, although there are exposures within 2 or 3 yards on both sides of it on the upper path ; but I have an old note (written in 1887) and illustrated by a sketch, that there was then a low section across it on the pathway showing it to have a southward inclination of 37°. Looking at this great feature (especially in the winter, when the woods are leafless) from the other side of the Gap, the angle was found, on an average of several measurements, to be 35° from the horizontal.[1]

In short, it is clear that the rupture is a true thrust-plane, and the features to which it gives rise resemble in every way those of the North-West Highlands of Scotland. It may be designated the Bella-Vista Thrust-plane (see fig. 8, p. 458).

The bedding of the *Caninia* Oolite riding on this thrust-plane dips at no less than 65°, so that the beds must be truncated by the thrust at an angle of 30°. The Coal Measures below it undulate at angles varying from 14° to 35°, rising to 90° close to the thrust, where they are described in my old note as contorted, and the dips now visible indicate this contortion to be a sharp isoclinal overfold. The *Caninia* Oolite at the thrust is traversed by lines of mylonitic deformation, and its texture is to a considerable degree obliterated. This mass of oolite, which does not reappear on the eastern side of the Gap, and also dies out rapidly south-westwards, is thus a double wedge or lenticle, about 60 feet thick, the internal structures of which are inclined at a much higher angle than that of the wedge as a whole.

The wedge of oolite, thinning down the dip, is seen to pass under limestones belonging to the upper part of Z_1, to which we can look up vertically from it as we can to the oolite from the Coal Measures. The plane whereon they rest is consequently that of another thrust. This also does not appear to be exposed, but its inclination seems to be a degree or two higher than that of the Bella-Vista Thrust-plane, and it may, therefore, be regarded as truncated by and carried forward on the latter. A few yards farther south-east, the Z beds are seen to be crushed and traversed by steep minor thrusts.

What, now, is the nature of the western boundary of the Coal-Measures ? They end at a place where there is an abrupt change in the direction of the steep-wooded bluff, and (dipping 22° south-

[1] The features on the eastern side of the Gap are less pronounced ; but the line, as traced down through the steep woods, indicates the same angle.

eastwards at the foot of the bluff, east of the quarry at O.D. 194·9), fail to pass up on the dip over the limestones of the Portishead–Clevedon ridge. The change of feature is, therefore, determined by a strike-fault, which, however, cannot be traced on towards Clevedon, and does not seem to have a throw of more than 50 or at most 100 feet. Quickly escaping (by reason of a south-westward rise of the basal plane) from this fault, the boundary, marked by a pronounced escarpment, curves round on the high bare down, and is truncated against the Bella-Vista Thrust-plane, for the Coal Measures (traceable by fragments in the ploughed land across the road) wedge out about 140 yards beyond Park Cottages, and have disappeared on the crag near Hampton House. Manifestly, they too rest on a moderately inclined plane. Whether, as believed by A. Vaughan and F. Dixey,[1] there be unconformity, the whole of the Viséan, with apparently the Lower Coal Measures as well, having been locally removed by inter-Carboniferous erosion, is a question that will not be discussed in this paper. But, independently of that question, there is reason to suspect that the base is cut out, for the lowest visible sandstones on the wooded bluffs are buckling over, as if driven forward on a thrust-plane. Should serious unconformity be eventually proved, this thrust need not be of much tectonic importance. In any case, the plane, whatever its nature, is overstepped by the Bella-Vista Thrust-plane at the point indicated.

The last of the ruptures which emerge upon the wooded bluff is one that determines another sudden change in the direction of that bluff, at the nook of Bennett's Ripple, where the features clearly indicate that its inclination is south-eastward. Yet, suddenly widening the outcrop of the *Caninia* Oolite, it must be an upthrow to the south-east, and is therefore interpreted as a minor thrust. There are indications that the overriding beds, which cannot be far from the base of the oolite, and exhibit the characters of the passage from the *laminosa* dolomite, are sharply overfolded. But this minor thrust soon dies out south-westwards.

(*c*) The Park Road.

The position of the Bella-Vista Thrust-plane can again be fixed to within a few yards in a small gully of the crags below the upper Park Road, a little to the east of Hampton House, where its angle appears to be reduced to about 15°. Here, having cut out the upper thrust and overridden the Coal Measures, it is driving Z_1 beds of the southern ridge on to undisturbed *Caninia* Oolite, not of that ridge, but of the northern ridge: that is to say, on to a much lower tectonic horizon than that of the oolite-wedge of East Clevedon Gap.

(*d*) Littleharp and Salthouse Bays.

Minor disturbances, such as curvature of the strike, have long been visible in places upon the Clevedon coast. But the stormy

[1] Q. J. G. S. vol. lxi (1905) pp. 228, 232; Geol. Mag. 1915, pp. 312–16.

tides of January 1920, by laying bare the foreshore in Littleharp and Salthouse Bays, showed that the K_2 beds and the *Clathratus* subzone of Z_1, instead of disappearing finally on the dip at the end of the great foreshore section of Clevedon Bay (described by A. Vaughan), are twice repeated.[1]

Thus, the apparently abnormal thickness of Z beds was accounted for, and the existence of two considerable ruptures was revealed. The inclinations of these ruptures, which are exposed only on the foreshore, have not been, so far, clearly observable; but on the north side of Littleharp Bay, immediately below the northern one, there is a belt of unmistakable minor thrusting, underlain by a belt of sharp folding, which leaves no doubt that both of them are true thrust-planes. They strike towards the Bella-Vista Thrust-plane; an interruption, caused by a disturbance presently to be described, makes it difficult, however, to be sure of the precise tectonic horizons.

(*e*) Dial Hill (fig. 9, p. 458).

This conspicuous hill, which nearly reaches the 300-foot contour, presents a curious problem. It rises to a height of 60 feet above the elevated platform of the Old Park, and that with singular abruptness, being bounded on all sides by steep, sometimes even craggy, features. Its rocks dip at about the same average angle as do those of the surrounding platform, with, however, sharp local variations. But when, starting from the Z_2 beds at the roadside overlooking the Congregational Church, we proceed along the strike, we find that these beds, instead of ranging over the summit, suddenly disappear at the foot of the bounding feature, where we meet with *Caninia* Oolite, underlain by a rock which is regarded as a crystalline modification of the *laminosa* dolomite, although its upper part may be a modification of the lower beds of the oolite itself, developing locally in the vicinity of disturbances. Precisely the same relations reappear at Old Park House at the other end of the hill. Further, we find that the base of the unbroken *laminosa* dolomite at the roadside above the Congregational Church runs up against the same bounding feature, and disappears in like manner. Dial Hill itself is composed of the *Caninia* Oolite and *laminosa* dolomite aforesaid, save that on its north-western escarpment a wedge of crinoidal limestone of the type common in horizon γ rises from beneath the latter. It is, however, only some 25 feet thick, and not only does it wedge rapidly out in both directions, but *laminosa* dolomite rises again from beneath it. The beds on the hill, which dip at angles varying from 35° to 50°, show signs of disturbance.

Is a tectonic interpretation of these phenomena feasible? Plainly, as before, there is rupture; but what is its nature? Let

[1] The local details of this interesting discovery have been communicated to the Bristol Naturalists' Society. Here it may suffice to say that the occurrence of the characteristic Z_1 fauna and of *Cleistopora* aff. *geometrica* places the two horizons beyond all doubt.

us compare the probabilities of normal faulting and overthrusting.[1] For the first method we must postulate a pair of faults running north-west and south-east in the same general direction as the post-Triassic fault of Ladye Bay, which is about half a mile away to the north. Now, where such faults must cut the boundaries of the several zones and sub-zones (not to mention the base of the Trias of the seaboard if the faults be post-Triassic), perhaps a dozen intersections in all, those boundaries show no signs of displacement. Nor would the faults account for the wedge of crinoidal limestone, or for the curving boundaries near Old Park House. Significant also is the fact that, whereas the Ladye Bay fault[2] gives rise to a strong feature all along its course, these do so only at Dial Hill itself, and develop no features whatever in the rest of their course. Why should two faults cross a tract composed of a number of rocks with very different powers of resistance, and yet produce no features whatever except, in each case, just at the sides of the mass which they are postulated to explain? They also raise a difficulty in connexion with the Hill-Road-Crag disturbance which will be considered later (p. 464).

Is any simpler hypothesis available? We know that over-thrusting does exist in several parts of Northern Somerset, as at Weston-super-Mare, Vobster, and Radstock; while the overthrust at Clifton is on one of the two Clevedon lines of strike. We now know, too, that there is powerful thrusting less than 200 yards from Dial Hill. The Radstock thrust, moreover, is at an extremely low angle, if not horizontal. Now, from whatever direction we look at Dial Hill. its aspect is, despite the high dip of its beds, in every respect that of an outlier. Let us suppose it to be, like many such hilltops in the North-West Highlands,[3] an outlier from a major thrust-plane (see fig. 9, p. 458). All the phenomena that it reveals become at once intelligible. Even its little wedge of crinoidal limestone, so curiously overlying part of its *laminosa* dolomite, receives an explanation as a wedge driven up on a minor thrust, piling up the beds which ride upon the major thrust-plane.[4] But of what thrust is it an outlier? From the low angle of the sole the main outcrop is not likely to be close by. The most likely one is the dominant thrust of Clevedon, the Bella-Vista Thrust-plane, whereon one wedge of steeply-dipping rocks at any rate is visibly riding. We have already seen reason to suspect that the angle of the Bella-Vista Thrust-plane is lowering in a south-

[1] The adjective 'normal' seems to suggest a sort of presumption in its favour. But, in the absence of junction-sections, no such *prima-facie* presumption is admissible. Indeed, there are districts, the North-West Highlands, for example, in which overthrusting is really the 'normal' type of rupture, the other kind being but an accessory.

[2] This fault ought, on the 1-inch reduction, to have been drawn with slight, but distinct, curvature.

[3] See 'The Geological Structure of the North-West Highlands of Scotland' Mem. Geol. Surv. 1907, fig. 25 & others.

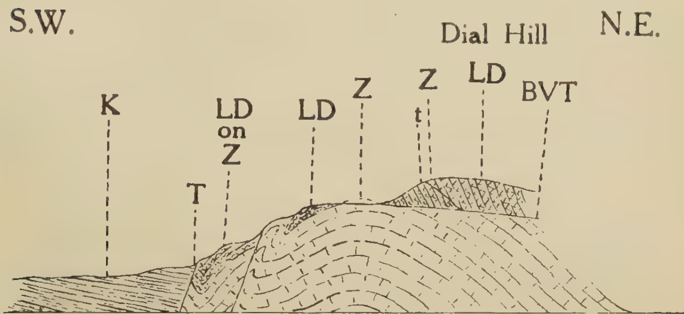
[4] Confirmation of this view will be found in connexion with another structure to be discussed farther on; see footnote on p. 464.

westerly direction. Let it bend over in a manner for which there are numerous precedents in the classic region of the North-West Highlands,[1] and an outlier from it could easily be taken in[2] on a gentle syncline at Dial Hill. The foregoing theory seems to possess the advantage of not being in conflict with any stratigraphical evidence, and of being in harmony with the general structure of the district.

(*f*) The Hill-Road-Crag Disturbance.

Running completely across the town of Clevedon is a great line of crag, which overlooks the 'Hill Road,' with a height, in places, of as much as 100 feet. Its trend being from north-west to south-east, is at right angles to the dominant strike, and it terminates the high platform about a quarter of a mile

Fig. 10.— *Section across the Hill-Road-Crag disturbance, on the scale of 12 inches to the mile.*



[Hill Road is at the point marked by T.]

K = *Cleistopora* Beds. Z = *Zaphrentis* Beds.
LD = *Laminosa* dolomite. T = Major thrust.
t = Minor thrust. BVT = Bella-Vista Thrust-plane.

south-west of the convergence of the two ridges. Above Christchurch it bends round from south-east to east, and dies away rapidly towards Mount Elton. That it is determined by a belt of disturbance is evident upon the map, where sub-zone after sub-zone is seen to be truncated at it. This disturbance is of pre-Triassic age, for it does not emerge upon the sea-cliffs of Dolomitic Conglomerate, and it passes beneath the base of that formation at Stancliff without causing any displacement. It is not simple, but includes three principal axes, with an aggregate width of about 50 yards. An attempt at a section across it is given in fig. 10, but attention is asked to the circumstance that, while crossing the strike within the belt of disturbance,

[1] *Op. cit.*, Mem. Geol. Surv. 1907, figs. 27 & 48.
[2] *Ibid.* fig. 49.

the section is along the strike outside that belt, so that those parts are merely diagrammatic. The beds within the belt are wrenched round through 90°, so as to strike directly across the dominant trend of the country. They bend down south-eastwards in a sort of large monocline, but this is followed by a sharp synclinal axis, and that by a rupture (nowhere exposed) at which the disturbance ends. Moreover, the monocline must be complicated by a subsidiary isocline, for a short narrow strip of the *laminosa* dolomite appears within it, and there is evidently also a subsidiary rupture in the middle of the belt. Where the crag-feature bends eastwards, the disturbance must be dying out, for at Mount Elton it seems to be represented merely by a few folds of small amplitude. That the whole of this transverse wrenching is later than the thrusting is certain, for it cuts off the Bella-Vista Thrust-plane completely near Hampton House, and that plane has not yet been identified with certainty on the south-western side.

The most striking feature of the belt, when studied on the map, is the long band of *laminosa* dolomite which has been traced along it from Hampton House to the Stancliff Trias.[1] Whence has this long band of the dolomite been brought? Certainly it cannot have come from the ordinary outcrop of that subzone, which is seen at Newton House and Hallam Hall. Moreover, the nip of dolomite at the isoclinal infold in the monocline must rest, not on Z_2 or γ, but on Z_1 beds 250 feet lower in horizon, which is an impossible overlap! We have seen, however, that wedges of the C-Zone, repeated and driven one upon the other, have been brought forward, probably on the Bella-Vista Thrust-plane, as far as Dial Hill. That hill we have seen reason to regard as a mere outlier, and similar wedges may well have extended 300 yards farther, if not much more than that. Suppose them bent over on the curve of the monocline. Then, in view of the gentle inclination of the thrust-plane at the outlier, which would keep their sole down to the 300-foot contour, quite a moderate displacement could bring them into the required position. The Bella-Vista Thrust-plane seems, accordingly, to have rolled over southwards on this remarkable disturbance.[2]

Owing to the monocline, the downthrow of the disturbance,

[1] Further investigation may show that this band is not really continuous, but interrupted by wedges of other sub-zones, such as Z_2, or the *Caninia* Oolite. Except in the public zigzag path which goes up the crag from the end of Bellevue Road, the whole belt of disturbance emerges in private gardens and backyards. All of these were examined, but in such places obscure exposures are liable to be missed.

[2] Incidentally (see p. 462), this carries confirmation of the proposed interpretation of Dial Hill. For, had the *laminosa* dolomite of the outlier been merely part of the ordinary outcrop of that sub-zone thrown forward between two faults, the high dip of their base (38° to 40°) would preclude them from being brought down in the necessary manner. In addition to which, there would be the impossible overlap on to Z_1 already mentioned.

as a whole, appears at first sight to be south-westwards. But a consideration (see Pl. XXXIX, fig. 3) of the zones and subzones which it brings against each other shows that its net effect is a considerable up-drive on the south-western side, and thus that the final rupture must more than counteract the effects of the monocline. In view of the evidence pointing to north-eastward isoclinal folding, that rupture may be regarded with probability as a steep northward overthrust, along the overdrive side of a deep isoclinal infold.

VI. Summary of the Tectonics of the Clevedon Area. (E. G.)

It thus appears that the tectonics are of true North-West Highland type. The Bella-Vista Thrust-plane drives various horizons of the Limestone Series on to the Coal Measures and on to limestones of lower tectonic horizons. Although its angle is as high as 35° at East Clevedon Gap, there is evidence that it bends over westwards, and that it survives as a gently synclinal outlier on Dial Hill. The rocks, both above and below, are several times repeated by minor thrusts. The thrust-plane, rolling over south-westwards as well, is driven back and up again on the transverse disturbance of the Hill Road Crag. Folding is everywhere subordinate to thrusting.

VII. General Interpretation of the Dynamics.

Let us now attempt a generalized picture of the dynamic significance of these phenomena.

The two Palæozoic ridges, with the Vale of Gordano between them, may be regarded as the remains of a large isoclinal infold with northward overdrive, deep enough to take the Coal Measures into its core. But it is really composite, for, towards Portishead, an isoclinal infold, which takes in beds as high as the *Caninia* Dolomite, is succeeded by an anticline, part of which is perceptible at Fore Hill. From the existence of Coal Measures at Clapton, we may infer that another syncline intervenes between the Fore Hill anticline and the main southern ridge. At Clevedon also, though every fold seems to be ruptured, the existence of two isoclinal infolds with an anticline between them is still discernible.

Towards Portishead there is an evident south-westward pitch; but at Clevedon it is a rise of lower beds on pitch which nips out the Coal Measures, brings up the K beds in Littleharp and Salthouse Bays, and is the true meaning of the convergence of the two ridges. Here, therefore, we have the south-western rim of the syncline, with a north-eastward pitch. Thus, considered as a whole, the major infold must be boat-shaped. The attempt to produce pure isoclinal folding was, however, unsuccessful. It found expression for the greater part, not in inversion, but in a succession of overthrusts, whereon the southern limbs were driven across the cores of the folds on to their north-western

limbs, the limestones of the south-eastern limb of one major infold being driven (as seen at Dial Hill) completely across the Coal Measures, where they narrowed on the rising pitch, on to the limestones of the north-western limb.

At each end of the district there is transverse disturbance. The north-east and south-west strike, though locally dominant, is, regionally considered, subordinate to the general east-and-west Armorican strike. At Portishead there seems to have been an attempt to resume the regional strike. But this resulted in rupture; and, as the local boat-shaped infolds were in this latitude rising on their pitch, they were driven along a succession of thrusts (figs. 3 & 4, pp. 451 & 452) over those beds in which the regional strike had been established.

At Clevedon there was again an attempt to resume the regional strike, resulting again in transverse disturbance with a generally northward impulse. It is to be noted, moreover, that the Bristol-Clevedon ridge, being itself on the regional Armorican strike, is unaffected by this movement, the Hill-Road-Crag disturbance dying out just where the limestones of the two ridges come together. Thus, transverse disturbance comes into being where the local strike was turning round into the regional, and only there. At Clevedon, moreover, it was the beds wherein the regional strike had been resumed that were driven upwards over those which retained the local strike. Finally, in this case, a major thrust-plane of the local strike became itself involved, being doubled into and driven up along the transverse corrugation.

EXPLANATION OF PLATE XXXIX.

Fig. 1. Generalized geological map of the Clevedon–Portishead area, on the scale of 1 inch to the mile, or 1 : 63,360.

2. Geological map of the Portishead Promontory, on the scale of 6 inches to the mile, or 1 : 10,560.

3. Geological map of Clevedon, on the scale of 6 inches to the mile, or 1 : 10,560.

Discussion.

Dr. J. A. Douglas referred to certain isoclinal infolds of the *Zaphrentis* Beds in the *laminosa* dolomites, and asked whether any indication had been observed of inversion of these beds. One of the diagrams exhibited by Dr. Greenly suggested that these were small plunging anticlines, connected with the overthrusting, rather than normal pinched-in synclines.

Dr. J. W. Evans asked what were the relative ages of the folding with an east-and-west strike and of that striking north-east and south-west. In the South-West of England the Armorican folding alternated between those two directions, but in both cases appeared to date from the same period of disturbance. The paper illustrated the great debt which geological science owed to the work of the late Dr. Arthur Vaughan, in elucidating the

stratigraphy of the Lower Carboniferous, and thus assisting in the solution of problems presented by structures in which those rocks were involved. His comparatively early death had been a severe loss to British geology.

Prof. O. T. Jones remarked that many of the structures, such as sharp folding and overthrusting from the south, described by the Authors, were familiar features of the Carboniferous rocks much farther west in Pembrokeshire. The transverse fault described by the Authors as later than one of the main strike-faults reminded the speaker of a tear-fault. Such faults commonly accompany intense folding and overthrusting; but, although in general later than these structures, which may be cut by them, they must be regarded as part of the same system of movements as the other structures, and are not necessarily an indication of recurrence of movement at a considerably later period.

Dr. Greenly, in reply, said that he did not think that there was any general inversion within the belt of transverse disturbance. At the isocline, indeed, there was no decisive evidence locally; but the Z beds on its south-western side, bending over, passed under the *laminosa* dolomites of the principal infold of the belt, and rose again from under them on the farther limb. It was, however, four years since he had seen the exposure.

With regard to the relative ages of the two strikes, there was room for speculation that one of them had been pre-determined by some older folding of Caledonian trend; but evidence was lacking, and he was inclined to agree with Dr. Evans's suggestion that the trend of the Portishead–Clevedon ridge was no more than a local deflection of the regional Armorican strike. He joined cordially in Dr. Evans's appreciation of the zonal work initiated by the late Arthur Vaughan. Without that zonal work, indeed, the study in tectonics now submitted would have been impossible.

19. AGE *and* ORIGIN *of the* LOUGH NEAGH CLAYS. By WILLIAM BOURKE WRIGHT, B.A., F.G.S. (Read February 27th, 1924.)

CONTENTS.

I. INTRODUCTION.

IN the years 1918 and 1919 the Department for the Development of Mineral Resources made an attempt to solve the problem of the concealed extension of the Tyrone Coalfield by putting down a bore near Coalisland. One of the secondary results obtained from a study of the cores was an approximate solution of the old question of the age of the Lough Neagh Clays. These clays, as is fairly generally known, occupy the ground around Lough Neagh in the North of Ireland; but, being for the most part at a very low level, and covered by a thick mantle of drift, they are poorly exposed. Previous to 1875, and recently to a less extent, they were exploited for pottery purposes by means of open and bell-shaped pits, and E. T. Hardman [1] records a number of sections obtained in this way. The only organic remains obtained from these pits were fragments of wood and woody tissue so highly carbonized as to be quite unidentifiable, and affording no trustworthy evidence of age. From general considerations, such as their superposition on the basaltic lavas, and the fact that they are overlain by the glacial drift, Hardman concluded (but apparently not without misgivings) that the clays were Pliocene and laid down during a period of greater extension of the present lake. The evidence now available relegates them to the Older Tertiary, and indicates that their deposition was previous to the Miocene folding and faulting, so that their apparent association with the lake may be merely the result of their escape from denudation in the low ground around it.

The difficulty of deriving a great thickness of very slightly ferruginous sediment from the denudation of a basaltic terrain does not appear to have troubled Hardman. It was first pointed out by Prof. H. J. Seymour in 1912,[2] and influenced him in the

[1] 'On the Age & Mode of Formation of Lough Neagh (Ireland), with Notes on the Physical Geography & Geology of the Surrounding Country' Journ. R. Geol. Soc. Ireland, vol. xiii (1875) p. 170.

[2] 'The Interbasaltic Rocks (Iron Ores & Bauxites) of North-East Ireland,' by G. A. J. Cole, S. B. Wilkinson, A. M'Henry, J. R. Kilroe, H. J. Seymour, C. E. Moss, & W. D. Haigh, Mem. Geol. Surv. Ireland, 1912.

direction of believing that the clays were derived from the denudation of the lithomarge of the interbasaltic zone so much in evidence between the Upper and Lower Basalt Lavas of the Antrim plateau. He was restrained, however, from regarding them as of interbasaltic age, since basaltic dykes, such as are usually found penetrating both the Upper and the Lower Basalts, are completely absent from the area covered by the clays. This seemed perfectly sound reasoning, but it left him with the necessary conclusion that, as the Upper Basalt could not be supposed to have been removed by denudation so as to expose the lithomarge beneath, it must originally have had a restricted area of distribution. He considered that this supposition was strengthened by the discovery at Claremont, on the northern shore of Lough Neagh, of an area of lithomarge uncovered by the Upper Basalt.

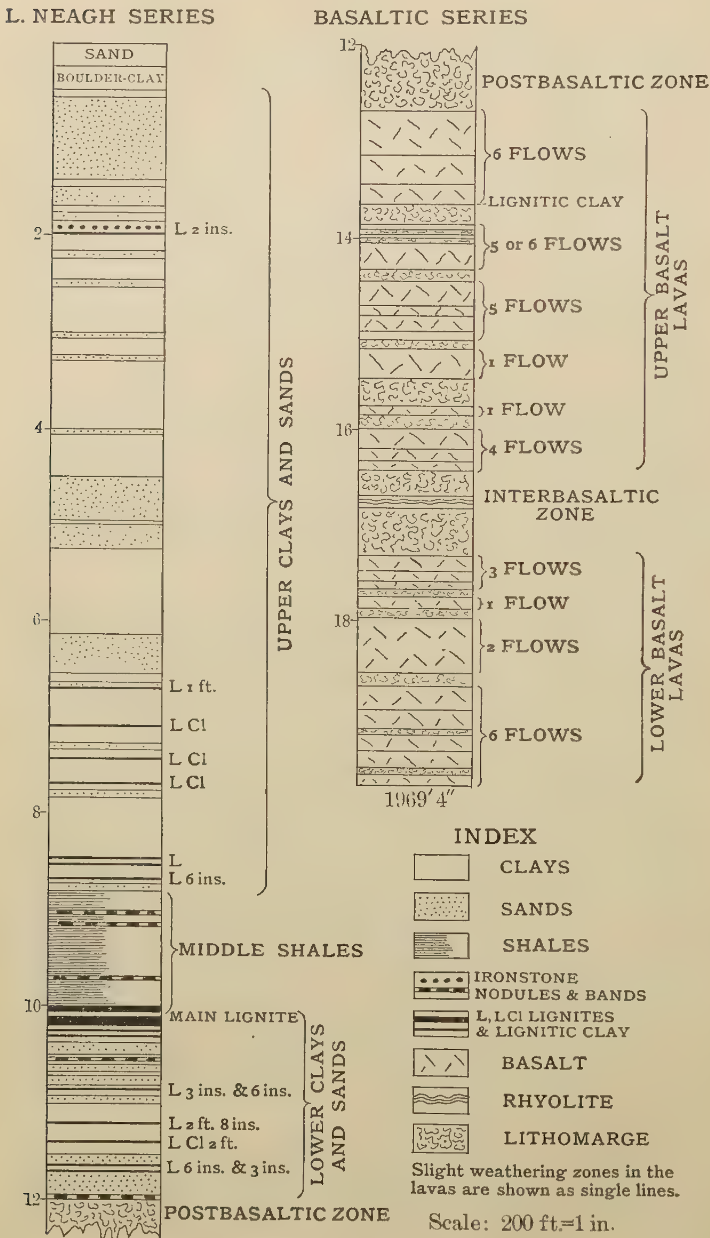
An excellent discussion of the problem in the light of recent studies of tropical weathering was given by the late Prof. G. A. J. Cole, in an appendix to the memoir quoted above, and the previous literature dealing with the clays being therein summarized need not be detailed here. As a solid contribution to our knowledge of the subject, however, mention should be made of Swanston's discovery of plant-remains in clay-ironstone nodules on the shores of Sandy Bay. These were investigated by Mr. J. Starkie Gardner, who describes them as

> 'most diversified, though usually small-leaved dicotyledons, which at first sight seem of very modern aspect. On closer examination, however, many are found to be characteristic of the English Middle Eocene, and others of the Lower Eocene. Others are common to Ballypalady, to Mull, and to Greenland' (Q. J. G. S. vol. xli, 1885, p. 91).

Cole, however, pointed out that there was no certainty that the nodules had been derived from the Lough Neagh Clays, and that they may possibly have come from the Interbasaltic Zone. With respect to the age and origin of the clays he came to no definite conclusion, but was inclined to regard them as post-basaltic in age and derived (as suggested by Seymour) from the destruction of the Interbasaltic lithomarges. The evidence now available from the Lough Neagh boring indicates that, while the clays have apparently been derived from the destruction of a zone of lithomargic weathering, this zone was of post-Basaltic age and derived in part from the destruction of the Upper Basalt Lavas. A new chapter, beginning with the cessation of volcanic activity, and ending in the episode of folding which initiated the first Lough Neagh, is thus intercalated in the Tertiary history of Northern Ireland.

The accuracy of the stratigraphical details given in this paper owe a great deal to the skill and experience of Mr. Ernest Williams, the engineer in charge of the boring at Washing Bay. Mr. E. B. Bailey, of the Geological Survey of Scotland, has read the manuscript, and has made some valuable criticisms.

Fig. 1.—*Section of the Washing Bay borehole, on the scale of 200 feet to the inch.*



II. Stratigraphy.

The site selected for the Lough Neagh Boring on the shore of Washing Bay (County Tyrone) was deliberately chosen, because it lay not far from what appeared to be the deepest part of the basin, and on this account was more likely to yield a successful result. The possibility of excessive depth was hardly considered, as the surrounding country gave no indication that it would be an important factor in the case. That the question of depth is a very serious one is, however, now shown by the fact that, when abandoned at close on 2000 feet, the bore had not yet penetrated the whole of the lavas.

The strata proved in the boring fall easily into the following subdivisions:—

		Thickness.	*Depth.*
	Recent Sands of Lough Neagh	20′	—
	Glacial Deposits	28′	48′
Lough Neagh Series.	Upper Clays and Sands	833′	881′
	Middle Shales	127′ 7″	1008′ 7″
	Lower Clays and Sands	187′ 5″	1196′
Tertiary Volcanic Series.	Postbasaltic Zone of Weathering	71′	1267′
	Upper Basalt Lavas	373′ 6″	1640′ 6″
	Interbasaltic Zone of Weathering	89′ 8″	1730′ 2″
	Lower Basalt Lavas	239′ 2″	1969′ 4″

Recent and Glacial.

Little information was obtained from the bore concerning either the recent sands or the glacial deposits. The 20 feet of brownish sand recorded at the top may be all postglacial shore sand; but, on the other hand, the lower portion of it may be glacial or fluvio-glacial. The $6\frac{1}{2}$ feet of bedded clay with its base at $26\frac{1}{2}$ feet is probably a glacial laminated clay. It is somewhat micaceous, and apparently quite unfossiliferous. The boulder-clay presents no points of special interest: it is the ordinary boulder-clay of the district, with quartzite and diorite from the Slieve Gallion region. Its base rested upon Lough Neagh Clays at a depth of 48 feet from the surface.

Lough Neagh Series.

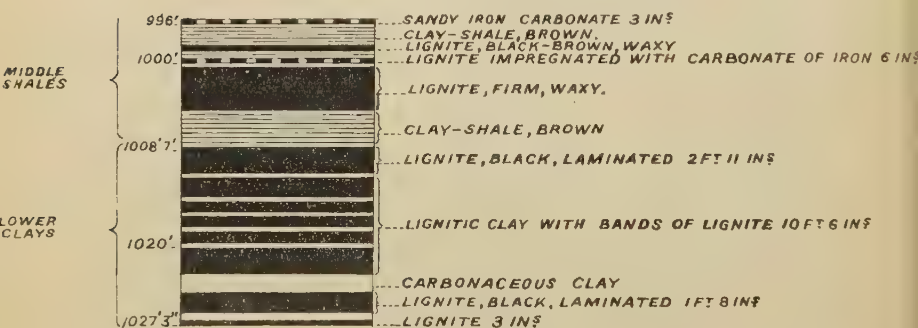
The Lough Neagh Series, where penetrated in the Washing Bay bore, had the somewhat surprising thickness of 1148 feet. It consisted largely of blue, grey, and white clays with sand-beds, lignite, and a few bands of carbonate of iron, very similar to that hitherto observed at the surface. The bore, however, revealed the occurrence, in the middle of the series, of a thickness of about 128 feet of a completely different type of sediment. These beds are perhaps best described as brown shaly clays approaching the character of oil-shales. They contain in places a considerable amount of bituminous matter, which can be observed by distillation

in a closed tube. Well-preserved fossil plants, as also shells of *Paludina* (*Vivipara*) and *Unio*, were abundant on certain horizons, and bands of carbonate of iron occurred at frequent intervals. Such variation in character affords sufficient justification for the tripartite subdivision shown above.

The Upper and Lower Clays and Sands can hardly be described as unfossiliferous, but few identifiable fossils have been found in them. Plant-remains are abundant, and twigs and obscure leaves can be made out; but the tissue is highly carbonized, and nearly all characteristic features are destroyed. The state of preservation in the Middle Shales is in striking contrast to this. Leaves exhibit the most delicate venation, and Prof. T. Johnson and Miss J. Gilmore have been able to obtain from them preparations of the epidermis showing perfectly the cellular structure with stomata and glands.

At the junction of the Middle Shales with the Lower Clays, between the depths of 999½ feet and 1025 feet 8 inches, there were some thick bands of lignite and lignitic clay showing the section exhibited in the appended diagram (fig. 2).

Fig. 2.—*Section of the main lignite in the Washing Bay bore, on the scale of 20 feet to the inch.*



It is of interest to note that the upper beds of the lignite lie in the Middle Shales, while the lower beds are in the Lower Clays, and that the character of the lignite is essentially different in the two series. That in the brown shales is brown and waxy, while that in the clays is black, brittle, and carbonized. The brown lignite between 1000 and 1005 feet has also a lower specific gravity, a much lower ash-content, and a somewhat higher yield of volatile matter than any of the beds beneath. It is capped by about 6 inches of very hard lignite impregnated with carbonate of iron.

The Upper Clays and Sands consist of 833 feet of alternating sand and clay, the clay being the predominant element. The thickest bed of sand has its top 7 feet below the base of the drift,

and has a depth of about 85 feet. From this downwards the sand and clay occur in frequent alternations, the clays having generally a bluish-grey colour turning to various shades of pale and deep yellow or greenish-yellow when dry, owing doubtless to ferruginous impurities. In places this iron stain is absent, and the clay dries to a greyish white, showing that the iron content of the stained beds is probably original. Below a depth of 350 feet the iron content is not so marked. The presence of carbonaceous matter, when intimately admixed with the clays, imparts to them tints varying from pink to purple. There is only one well-defined bed of lignite in the upper part of the series. It is 2 inches thick, and occurs at a depth of about 196 feet. From this depth down to 670 feet there is a complete absence of lignite, except as fragments embedded in the clay.

The clays also vary indefinitely in grade, and in many instances contain a distinct sandy element, the sand being relatively coarse in comparison with the clay matrix. When the sand becomes very abundant the admixture approaches the condition of moulding-sand, there being evidently a great distinction between the two grades of which the material is composed.

The series as a whole is almost entirely devoid of bedding on a small scale, but certain exceptions to this should be noted. Laminated beds occur at depths of 216, 242, and 258 feet respectively, and clays with carbonaceous laminæ occur at 298 feet. Three very remarkable instances of banded clay occur between the depths of 315 and 350 feet. The uppermost of these three, at a depth of 315½ feet, shows a banded belt with three alternations in colour, the bands, numbering six in all, being from half an inch to 1 inch thick. The next instance, at a depth of 338 feet, embraces 15 inches of banded clay containing eight alternations or sixteen bands; the dark bands are from a quarter of an inch to half an inch thick and 1 to 4 inches apart. Some of the wider bands are slightly sandy. The third instance, at a depth of 347½ feet, is very similar to the second, and contains the same number of bands. There is also some banded clay at a depth of 490 feet, showing in all about four alternations, 1 inch being dark and 2 inches light in colour; and a stiff brown clay at 697 feet shows laminations at the base, brown laminæ a quarter of an inch thick alternating with grey laminæ 1½ inches thick.

An interesting bed, 18 inches thick, occurs at a depth of 325½ feet. It consists of coarse clayey sand of a bluish colour when fresh, but weathering yellow. The late Prof. G. A. J. Cole made an examination of the minerals contained in this sand, and found that they include greenish mica, coarse angular quartz-grains, a little milky vein-quartz, fresh cleaved felspar, numerous rounded grains of glauconite, and a little zircon. There appears to be also present a considerable quantity of decomposed felspar passing into kaolin.

The clays, from 535 feet down to the base of the upper series at 881 feet, are predominantly much whiter than those above. White

clays with a peculiar primrose-coloured flecking occur at $684\frac{1}{2}$, at 703, and at 814 feet respectively. Sands are not so abundant as in the beds above. Beds of lignite are, on the other hand, much more frequent. There are in all eight well-defined lignitic bands, as well as a good many carbonaceous clay-bands, in a total thickness of 210 feet between the depths of 670 and 880 feet. These vary in thickness from a few inches to a foot. At 712 feet a lignitic clay contained twigs, and in a similar clay at 769 feet are fragmentary leaves and stems.

The first well-preserved plants, however, occur in the Middle Shales, which lie beneath a sand-bed whence artesian water was obtained at a depth of 881 feet. Here a complete change in the type of sedimentation sets in. The clays down to this point are white and grey, and entirely devoid of any structure that would entitle them to be called shales. Below this depth, down to a depth of 1008 feet 7 inches, they are brown and of a distinctly shaly nature. When the cores were drawn they were of a deep brown colour, in some instances almost black, but they dried out to a distinctly lighter shade. Some beds, especially those of a deeper tint, yield a certain amount of oil in the closed tube; but none of them seem to be sufficiently rich to be of any economic importance. Bands of carbonate of iron occur at frequent intervals, some of them being extremely hard and others showing only a mere impregnation of the clay. Plant-remains, wherever they occur, are beautifully preserved, but are more abundant at certain levels. Remains of *Paludina*, both shells and opercula, were found at many horizons, and a shell resembling *Unio* at one horizon. Plant-remains occurred at 898, 901 to 904, 906, 909, and 930–931 feet respectively. *Paludina* and *Unio* occurred at 898 to 899 feet; *Paludina* alone at 901 to 902 feet, 905 feet, 907 feet, 913 914 feet, 928–929 feet, and 989 feet. These fossils have all been found in the shales, none having up to the present been discovered in any of the ironstone bands.

At a depth of $998\frac{1}{4}$ feet the bore entered a 9-inch bed of brownish-black lignite, of waxy appearance. Beneath this came 6 inches of shale, and then lignite once more for a depth of $5\frac{1}{2}$ feet to 1005 feet. This lignite was firm, brown, and waxy, like that in the bed above, and had its upper 6 inches impregnated with carbonate of iron, the woody fracture being perfectly preserved. Beneath the lignite there was a thickness of brown waxy clay with lignitic bands to a depth of 1008 feet 7 inches. The next item was 2 feet 11 inches of lignite, but of so completely different a character that the base of the middle series of brown shales must be drawn at this point. Above this level the lignite clearly partakes of the nature of the brown shales with which it is associated, but from here downwards it is black, brittle, laminated, and highly carbonized, resembling the lignitic bands of the Upper Series of clays and sands.

The lignite, 2 feet 11 inches thick, which forms the upper

member of the Lower Clays and Sands, gives place at a depth of $1011\frac{1}{2}$ feet to lignitic clay, with bands of lignite, extending to a depth of 1022 feet. The core from this bed was much broken, some 5 feet in the centre being almost reduced to powder. Samples tested seem to indicate that the lignite is extremely impure and clayey. Beneath it are alternating bands of carbonaceous clay and lignite to a depth of $1027\frac{1}{4}$ feet, the carbonaceous clay being similar to that found in the Upper Clays. From this down to the base of the series at a depth of 1196 feet grey and white clays alternate with beds of sand, and lignites occur at frequent intervals. Most of these lignites are only a few inches thick, but a bed 2 feet 8 inches thick occurs at 1120 feet, and another, 2 feet thick, of impure clayey lignite at 1139 feet 8 inches. A 4-inch band of carbonate of iron occurs at a depth of 1052 feet 10 inches, and there are some brownish-grey clays with plant-remains at $1142\frac{1}{2}$ feet. The base of the series is formed by 28 feet of fine grey sand, beneath which is a 2-inch band of carbonate of iron, of a bluish mottled colour and having cavities filled with siderite. This rests upon lithomarge, and marks the base of the Lough Neagh Series at a depth of 1196 feet.

Beds below the Lough Neagh Series.

The beds below this only concern us in so far as they afford evidence bearing on the problem of the age and origin of the clays. They consist of the series known in Antrim as the Upper and Lower Basalt Lavas, and the intervening Interbasaltic Zone, the last-mentioned being a belt of lateritic and lithomargic weathering of amazing depth. To these well-established members of the Antrim succession the evidence of the bore now adds a fourth, which it is proposed to call the Postbasaltic Zone of Weathering. This is 71 feet deep, and is composed in the main of grey and red lithomarge. It clearly represents a period of decomposition and weathering of considerable duration subsequent to the last local outpourings of the Upper Basalt Lavas, and before the deposition of the Lough Neagh Clays. The upper 5 feet of the lithomarge dries out white, finely mottled with grey, and contains a few rudely pisolitic and slightly ferruginous pellets. The white matrix looks more like kaolin than bauxite. Below this is ordinary red and grey lithomarge.

The Upper Basalt Lavas, the decomposition of the upper members of which produced the Postbasaltic Lithomarge, extend for 444 feet below the base of the Lough Neagh Beds to a depth of $1640\frac{1}{2}$ feet. The whole series differs rather remarkably from that seen in the north and east of Antrim. The lava-beds are not as massive, and they have suffered considerably more decomposition of a lithomargic type. There are altogether between twenty-one and twenty-three flows which have not been destroyed

completely by subsequent weathering, and fourteen proved weathering zones in addition to that at the top. These zones vary from a few inches up to 27 feet 5 inches in thickness. Two of them, including that just mentioned, exceed 20 feet, and two more exceed 10 feet in thickness. There is thus no question that these Upper Basalt Lavas of the Lough Neagh Basin show a degree of weathering far in excess of that shown by the same series of flows in other parts of the plateau. Weathering zones, 20, 10, or even 5 feet thick, could not fail to be detected if they occurred between these lavas, where they occupy the tops of the hills in Eastern Antrim, much less so where they form the cliffs on the northern coast. Some conditions must, therefore, have existed in the basin, which led either to an accelerated or to a more prolonged weathering.

The most important of all the zones of weathering encountered in the bore was that between the depths of 1640½ feet and 1730 feet 2 inches. Its thickness of nearly 90 feet, and the fact that it lies between two thick series of basaltic lavas, makes it highly probable that it represents the Interbasaltic Horizon of Antrim. There is, however, very strong confirmatory evidence, in the shape of bauxite with idiomorphic and sometimes bipyramidal quartz, passing down into decomposed rhyolite, between the depths of 1667 feet and 1675¼ feet. The rhyolite contains quartz- and felspar-phenocrysts, the latter highly decomposed, and exhibits at its base a well-marked flow-structure. The relations appear to be very similar to those at Glenarm and Straid[1]; but no rhyolitic conglomerate was encountered in the bore.

Very little core was recovered from the upper part of the zone; such material, however, as was brought up seemed to indicate that it consists largely of bauxitic substances with the above-mentioned zone of decomposed rhyolite, and but little lithomarge, to a depth of nearly 1680 feet. From this to the base was entirely lithomarge of varying tints of grey, red, and purple. The red coloration is largely that of hæmatite, but certain horizons show a limonitic yellowish-red staining.

The Lower Basalt Lavas were penetrated to a depth of 240 feet below the base of the Interbasaltic Zone. Twelve flows in all were pierced, and there were nine weathering zones, two of which exceeded 10 feet in thickness. There appeared to be no bauxitic material present in any of the zones, which were all composed of rich red lithomarge. Weathering in these lower lavas appears also to have been more intense than in other parts of the plateau, but they do not, so far as they have been proved, seem to have suffered to the same extent as the upper series.

[1] See 'The Interbasaltic Rocks of North-East Ireland' Mem. Geol. Surv. Ireland, 1912.

III. Fossil Plants and Mollusca.

The Washing Bay boring has yielded the first identifiable plant-remains referable with certainty to the Lough Neagh Series. These have been studied with the most minute care by Prof. T. Johnson and Miss J. Gilmore.[1] Microscopical preparations of the tissues have been made, and comparisons instituted with all available recent and fossil material, so that the determinations may be regarded as the high-water mark of what is attainable in that very difficult subject the palæobotany of the Tertiary Era. The floral list published up to the present is, however, a small one. The presence of *Sequoia couttsiæ* Heer, and of three new species of *Dewalquea* S. & M., *D. hibernica*, *D. fraxinifolia*, and *D. denticulata*, is considered as established. *S. couttsiæ* is known also from Bovey Tracey in Devon, from the Interbasaltic Beds at Ballypalady in Antrim, and from Disko in Greenland. A number of species of *Dewalquea* have been described as occurring in the Upper Cretaceous from Alabama to Greenland, and in deposits of the same age in Westphalia and Bohemia, in the Lower Eocene of Gelinden in Belgium, and in the Lower Oligocene of Italy.

The wood found at various horizons, including that forming the main lignite horizon, is referred by Prof. Johnson & Miss Gilmore to Gothan's composite genus *Taxodioxylon*, formerly embraced by Gœppert in his *Cupressinoxylon* type. By a process of exclusion of the other families included in this genus, they conclude that the wood is that of a *Sequoia*, probably *S. couttsiæ* Heer, the leaves, cones, and twigs of which are associated with it.

It is clear from the smallness of this flora, the fact that three of the species determined are new, and the generally unsatisfactory state of the subject, that no confident conclusion can be drawn in regard to the exact dating of the beds. The authors cited are, however, of the opinion that the presence of *S. couttsiæ*, identical in every detail with that described by Heer from Bovey Tracey, indicates an Upper Oligocene age for the Lough Neagh Beds, a conclusion which is quite in accordance with the known geological facts. They also call attention to a very striking circumstance regarding the dominant type of foliage found in both these localities. It appears that the living species of *Sequoia* are dimorphous as regards their foliage, the leaves being in part squamiform and adpressed, and in part subulate and spreading. Mr. J. Starkie Gardner[2] has made the interesting observation that when *S. sempervirens*, from the mountains of California, is introduced into a warmer climate, such as that of Madeira, it develops more of the squamiform adpressed type of foliage, which, therefore, appears to be an

[1] 'The Occurrence of *Sequoia* at Washing Bay' Sci. Proc. R. Dublin Soc. n. s. vol. xvi (1921) p. 345; 'The Occurrence of *Dewalquea* in the Coal-Bore at Washing Bay' *ibid.* p. 393; and 'The Lignite of Washing Bay (Co. Tyrone)' *ibid.* vol. xvii, p. 59.

[2] 'British Eocene Flora' vol. ii (1883) p. 35.

adaptation to heat, serving in all probability the purpose of checking transpiration. As this is the dominant form in the specimens from the Lough Neagh Beds and from Bovey Tracey, we obtain, therefore, a definite indication of the climatic conditions during the deposition of the series, as well as an assurance that these conditions were much the same in the two localities cited.

The *Paludina* and *Unio* remains were submitted to Mr. A. W. Stelfox, who in turn forwarded them to Mr. R. Bullen Newton, I.S.O., F.G.S. In his reply, Mr. Newton says:—

'The specimens are too compressed and almost inadequate for serious determination. The *Viviparus* remains appear to be related to *Paludina lenta*, var. B, described and figured by John Morris (Q. J. G. S. vol. x, 1854, pl. ii, fig. 23 & p. 160), from the Lower Eocene (Woolwich and Reading Beds), of New Cross (found also at Peckham, etc.), a form said to possess (1) a somewhat ovate aperture; (2) five or six rounded volutions with an obtuse apex; (3) a conical shape; and (4) a smooth surface—a shell now regarded by M. Cossmann as referable to *Paludina suessoniensis*, of Deshayes, from the Thanetian (= Lower Eocene) of France, and which had previously been named by A. d'Orbigny *Paludina sublenta* ('Prodrôme de Paléontologie' vol. ii, 1850, p. 299).

'The Lough Neagh examples show no exposed apertures, while the general contour is relatively wider, and, therefore, more broadly conical than that figured by Morris. Among your specimens is an operculum of *Viviparus*.

'The Unioniform remains appear to be related to a Lower Eocene (Woolwich and Reading Beds) form figured by S. V. Wood ('Monograph of the Eocene Bivalves of England' Pal. Soc. 1877, vol. i & Suppl. pl. A. fig. 6, p. 1) as *Unio michaudi* (?), of Deshayes, which in my opinion is a wrong determination, the English shell being a long way removed from the true *U. michaudi* (see Deshayes, 'Description des Animaux sans Vertèbres' vol. i, 1860, p. 802, and pl. lxii, figs. 1–5). I am, however, without any French or English shells for comparison, and can only speak from the published figures.

'The plant-remains are too imperfect for determination. A few years ago I determined some leaves and an aperture of a possible *Viviparus* sent to me by Grenville Cole from the ferruginous deposits of Lough Neagh, which have been mentioned by Cole in his memoir on 'The Interbasaltic Rocks of North-East Ireland' (Mem. Geol. Surv. Ireland, 1912, p. 124). I have preserved photographs of those specimens. I think that your specimens and those of Grenville Cole belong to the oldest Eocene, and may even be Uppermost Cretaceous, and, if the latter, they are comparable with certain lacustrine or fluviatile remains found in the Intertrappean Beds of the Deccan Trap Series of India, as also with similar deposits of South Africa, to both of which I have recently referred in Ann. & Mag. Nat. Hist. ser. 9, vol. v (1920) pp. 241–49. The imperfection of your specimens, however, will not allow me to be more definite upon the subject.'

The apparent discrepancy between the age thus indicated by the plants and that indicated by the animals need not cause us any concern. Neither the state of preservation of the fossils, nor our knowledge of related forms, is such as to warrant any great precision. The important point is that both lines of evidence agree with that of the stratigraphy and tectonics of the area in pushing back the age of the Lough Neagh Clays to the Early Tertiary, if not even farther. These beds are certainly not Pliocene.

IV. The Age of the Lough Neagh Series.

We have just seen that there is very good palæontological evidence for regarding the Lough Neagh Beds as of early Tertiary age rather than Pliocene, although there still remains considerable doubt as to whether they are Miocene, Oligocene, Eocene, or even late Cretaceous. It now remains to be considered whether any other evidence can be brought forward to confirm this conclusion or to narrow down in any way the rather wide limits assigned.

An indication of the early Miocene or pre-Miocene age of the series is involved in their apparent relation to the earth-movements which affect the lavas, and can hardly be presumed to be any later than Miocene. The depth of the Lough Neagh Beds at Washing Bay proves their dip inwards towards the central axis of the Bann Syncline[1] to be quite as great as that of the lavas. The Lough Neagh Series is apparently folded with, and probably to nearly the same extent as, the upper portions of the lava series. It has probably also been affected by the same faulting as that to which the lavas have been subjected. The lignite which occurs at 1000 feet in the Washing Bay bore is almost certainly the same as that which crops out at Killycolpy some miles away to the north. This difference in level might, of course, be caused by an unknown dip of 5° between the localities; but such a high dip has never been proved in the series, and it would need to be very much higher if the strike is presumed to follow the margin of the clays. It is much more likely that the displacement is due to the throw of the Coalisland-Templepatrick Fault, which is now supposed to take a course along the northern shores of Washing Bay and Lennymore Bay, and to displace the Lough Neagh Beds as shown in the map (fig. 3, p. 480). The ground on both sides of the Lough has been examined, and there is no surface-evidence conflicting with such an interpretation. Moreover, some explanation was badly needed of the much greater spread of the clays south of this line. Indeed, had Hardman not been obsessed by the idea that the clays were deposited in a former extension of the present lake, and therefore probably Pliocene, he could hardly have missed the obvious inference that this powerful fault, which is visible on both sides of the lake, was responsible for the incoming of a greater area, and presumably also of a greater thickness, of the Lough Neagh Beds south of it.

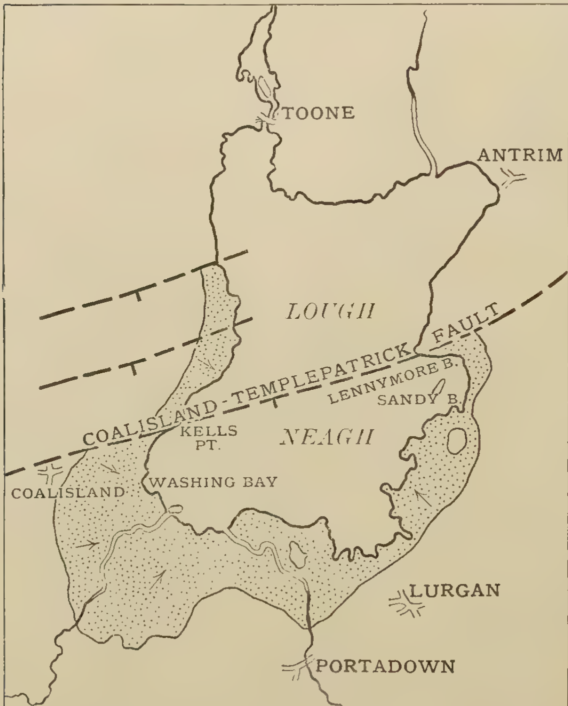
We see thus that the geological conditions under which the deposits occur put a fairly definite later limit to the age of the series. It remains to be considered if in any way an earlier limit can also be indicated. A deduction recently put forward by Mr. E. B. Bailey[2] regarding the climatic conditions of the Late Cretaceous has a distinct bearing on the problem. Mr. Bailey

[1] See W. B. Wright: 'An Analysis of the Palæozoic Floor of North-East Ireland' Sci. Proc. R. Dublin Soc. n. s. vol. xv (1919) p. 629.

[2] 'The Desert Shores of the Chalk Sea' Geol. Mag. vol. lxi (1924) p. 102.

having discovered, between the basalt-lavas and the Senonian beds of Mull, off the western coast of Scotland, considerable deposits of millet-seed sand accompanied by silicification of desert type, and finding on inquiry that millet-seed sand was a common residue of the otherwise remarkably pure Chalk, drew the conclusion that a desert climate characterized Northern Europe during the Late

Fig. 3.—*Sketch-map showing the probable relation of the Lough Neagh Beds to the Coalisland–Templepatrick Fault, and other faults on the north.*



[The Lough Neagh Beds are dotted. Scale: 1 inch=8 miles.]
For 'Toone', read 'Toome.'

Cretaceous Period, and that the possession of desert shores was the long-sought cause of the clearness of the Chalk sea.

Now, this appears to be perfectly sound reasoning. Desert is proved to have existed in the West of Scotland at this period by the occurrence of two distinct types of desert phenomena. One of these, the millet-seed sand-grain, is preserved in the Chalk over a wide area. The climatic conditions were, therefore, fairly general

so far as Northern Europe was concerned, and these conditions supply an explanation of the absence of river-borne sediment in the sea. It is going but a step farther to say that, so long as chalk was deposited, the climate must have been more or less desert, or in other words, desert conditions probably persisted to the top of the Danian, takiug this latter term in the sense in which it is understood in the type area of Denmark, but perhaps not including the French and Belgian formations (Montian and Maestrichtian) which are paralleled with it. This line of reasoning, therefore, indicates that the plant-beds of the British volcanic province are younger than the Danian of Denmark. There is, on the other hand, no clue to their relation to the Montian and Maestrichtian, which are unconformable to the Chalk below, and have a fauna of a transitional character.

V. Origin of the Clays and Sands.

The character of the Lough Neagh Beds raises some interesting problems, which, however, cannot all be solved in the present state of our knowledge. The main type of sediment is a grey or white clay of varying degrees of fineness and only showing traces of bedding at rare intervals. The principal ingredient is probably kaolin, and the presence in some of the clays of white flecks resembling kaolinized felspars confirms this view. No calcareous beds were found, the only carbonate noted being siderite, which was quite subordinate in quantity and confined to certain thin beds. As has been pointed out in the introduction, the difficulty attending the derivation of such a clay from the denudation of a terrain largely basaltic is at first sight very considerable, but it diminishes in the light of the information derived from the Washing Bay borehole. The source of the clay was not the unaltered basalt itself, but the 70 feet or so of soft lithomarge with which it was capped at the beginning of the Miocene movements that deformed the lava plateau and initiated denudation. With such a depth of weathered subsoil spread extensively over the catchment-area of the rivers tributary to the lake, an enormous amount of loose and easily movable material was available, so that we may well cease to wonder at the thickness of the series.

That kaolin is one of the principal constituents of lithomarge can readily be seen by examining a series of thin sections of this material, which will be found to consist of an opaque 'fuzzy' mass of finely divided iron-oxides with translucent patches and veins, as a rule finely crystalline and granular, but often showing the vermiform platy arrangement characteristic of kaolin. A second translucent mineral of distinctly lower birefringence is sometimes present, and may represent the essential constituent of bauxite.

Lithomarge is, therefore, a potential source of the kaolin of the Lough Neagh Clays. But there is still another character of these clays which points even more clearly to their origin. This is the remarkable concentration of titanium which they exhibit, as is

shown by the following analysis[1] of a clay from the depth of 1100 feet in the Washing Bay bore:—

	Per cent.
Water at 100° C.	1·80
Loss on ignition	8·70
Silica	54·10
Alumina	12·30
Ferric oxide	8·00
Titanium dioxide	10·50
Manganese oxide	0·25
Calcium oxide	0·94
Magnesia	0·83
Potash and soda	3·33
Total	100·75

Now, the concentration of titanium dioxide is a characteristic of lateritic weathering, as may readily be verified by reference to the series of analyses of materials from the Interbasaltic Zone of Antrim given by G. A. J. Cole & W. D. Haigh in the Survey Memoir on the Interbasaltic Rocks of North-East Ireland. It is to be regretted that only a single analysis of the Lough Neagh Clays is available for comparison; but, even alone, it gives considerable support to the idea that this clay has been derived from the denudation of a lithomargic terrain. We may, I think, with fair confidence regard the 70 feet of lithomarge at the base of the Lough Neagh Clays as the key to the great thickness of this formation.

The explanation of the comparative freedom from iron is not so simple. It is to be noted that there is no hæmatite-band at the top of the lithomarge of the Postbasaltic weathering zone at Washing Bay. If it were formed there we might have expected it to be preserved beneath the sediments, and it could not have been entirely missed in the boring. Its absence removes one possible source of iron in the clays; but, on the other hand, it calls for explanation. One can only suggest that there may be certain conditions of lateritic weathering, in which the iron, although abstracted by the vadose waters from a considerable thickness of rock, is never concentrated into a pan, but carried off into the drainage-water by seepages from the surface.

The Postbasaltic lithomarge itself, however, contains a large amount of disseminated iron, so that, if the relatively iron-free lake-clays are derived from it, some mechanism must be imagined by which the kaolin is concentrated in the lake and the iron-oxide removed. The explanation is probably to be found in the different state of division of the iron-oxide and kaolin in the lithomarge, the former being colloidal and the latter, as can be seen by examining a thin slice, largely crystalline. One may conceive of the larger kaolin-crystals being precipitated in the lake while the

[1] Analysis made for the Geological Survey of Ireland by Mr. George Brownlee, of the Irish Department of Agriculture.

far more finely divided iron-oxide remains in suspension, and is carried off through the outlet. The presence of an acid radicle, such as an excess of dissolved carbonic acid, in the waters of the lake might modify these relations, coagulating the colloidal iron and bringing it down at intervals to form the ironstone-bands found on certain horizons.

Colloidal alumina, if it existed in any quantity in the Post-basaltic Zone of weathering, would be similarly held in suspension, and possibly similarly precipitated in the presence of an electrolyte. It is to be regretted that the physical processes involved are so little understood that no safe conclusions can be drawn.

The presence in the Lough Neagh Series of great thicknesses of sand, predominantly composed of quartz, calls for explanation. There is an aggregate thickness of 285 feet of sand, of which 85 feet is in one bed near the top. There is also a large amount of sand disseminated in the clays. This sand is clearly not derived from the denudation of the rotted lavas, which cannot be supposed to have supplied quartz even in the smallest quantities. Its presence in such abundance demonstrates that the catchment-area of the tributary rivers extended beyond the basalt on to some type of siliceous rock. The schist-hills west of Slieve Gallion, the Trias, Old Red Standstone, and Millstone Grit of the Trough Valley, the Silurian strata on the south, and even the Newry Granite, may all have contributed to the formation of these sand-beds. Moreover, in the Postbasaltic Period, they doubtless suffered, equally with the basalt, the deep-seated lateritic weathering, the record of which is preserved beneath the lake-sediments. These rocks would give rise under such conditions to kaolin-sands like those of Cornwall, as easily denuded as the basaltic lithomarge itself, but unlike it in providing, as well as kaolin, an abundant supply of quartz-sand.

The Middle Shales form an interesting, but as yet unsolved problem. There can be no doubt that they mark some conditions of climate or deposition essentially different from those which characterized the beds above or below them. It is very difficult, however, to form any idea of what these conditions were. The essential difference from the ordinary clays of the series above and below appears to be the presence of a small proportion of hydro-carbons, which can be distilled off in the closed tube as oil. The presence of this material is in some instances barely discernible, but in others it is quite marked. These shales extend in the bore from 881 feet to 1008 feet 7 inches, a thickness of 127 feet 7 inches. They begin and end with equal sharpness, and are not interbedded with the white clays; but they embrace in their lower portion the upper 5-foot bed of the lignite formation, which partakes of their waxy bituminous character. These are the 'fossiliferous' beds of the series, but plant-remains are not more abundant in them than in the white clays; they are merely better preserved. *Paludina* and *Unio* are confined to the Middle Shales, the former being found throughout them.

VI. Summary of Conclusions.

Passing in review the results obtained from a study of the Washing Bay borehole, and qualifying our conclusions according to the amount of reliance to be placed on them, we arrive at the following summing up.

In the first place, it is now demonstrated that the Upper Basalts and the underlying Interbasaltic Zone are preserved in one locality at least beneath the Lough Neagh Beds. Whether they are so preserved over the main part of the area occupied by the clays is a matter for conjecture, and the question can probably only be settled by further boring. If the assumption, that the clays have been subjected in the main to the same folding and faulting as the lava series below, be correct, then it follows that the Upper Basalts and Interbasaltic Beds should crop out round the margin of the area covered by the clays. This outcrop has never been located, but it would lie in low ground thickly covered with drift. In view of the valuable deposits of iron-ore and bauxite elsewhere associated with the Interbasaltic Zone, its location might prove to be of great economic importance.

That there are dangers attendant on the assumption made is not denied, but it is difficult to find opportunity for the removal by denudation of the whole thickness of the Upper Basalts, either during the formation of the Postbasaltic lithomarge or during the subsequent deposition of the clays. The destruction of this generally massive series of lavas over the greater part of Antrim is more likely the result of the extensive denudation which followed upon the Miocene diastrophism, and resulted in the deep dissection of the basalt plateaux.

It may be regarded as a well established fact that the lavas beneath Lough Neagh, both Upper and Lower, have been much more deeply affected by lithomargic weathering than those of the higher portions of the Antrim plateau. This is true of the subsidiary as well as of the main zones of weathering. It is here tentatively suggested that this may have been due to a relatively low-lying swampy condition of the surface produced by gentle downwarping along the line of the Bann Syncline, continuous with the more pronounced folding along that line at a later date. Possibly, the absence of pisolitic iron-ore at the top of the main zones of weathering, which may be regarded as proved by the boring operations in the case of the Postbasaltic Zone and indicated with considerable probability in that of the Interbasaltic Zone, may be a connected phenomenon, the presence of swamp waters preventing the formation of iron-pan.

The occurrence of rhyolite in the Interbasaltic Zone beneath the Lough is a point of some interest, as it extends considerably the area affected by these eruptions. If, as has been supposed, the more valuable of the bauxite-deposits found at this horizon are derived from the decomposition of rhyolite, such deposits may well occupy considerable areas beneath and around the lake.

The suggestion that the Lough Neagh Clays may be of Interbasaltic age may now be regarded as absolutely disproved. They are not only superposed on the Upper Basalt, but separated from it by a deep zone of weathering.

Nevertheless, the discovery in them of *Dewalquea* and *Sequoia couttsiæ* connects them with the older Tertiary, so that they are certainly not Pliocene. Their apparent relation to the folding and faulting points in the same direction. Again, the climatic conditions demanded by the flora of the clays and that of the Interbasaltic Zone below seem to preclude their reference to the Late Cretaceous, for which Mr. E. B. Bailey's researches indicate a desert climate in North-Western Europe.

Finally, the very considerable thickness of the sediments is readily explained by the easily denudable nature of the lithomarge below, which must have covered a great part of the catchment-basin of the lake in which they were deposited. To account for the relatively feeble concentration of iron in the sediments a selective sedimentation is imagined to have taken place in the lake waters, whereby the kaolin was precipitated, and the more finely divided iron-oxides were carried off in the drainage-waters. The presence of a large proportion of quartzose sand proves that the tributary rivers extended far beyond the Basalt Lavas on to quartz-bearing rocks, the surface of which had no doubt been rendered equally easy of denudation as a result of the subtropical weathering of the period.

Discussion.

Major A. R. Dwerryhouse congratulated the Author on the important addition which he had made to our knowledge of the Lough Neagh Clays, and stated that, through the Author's courtesy, he had had an opportunity of visiting the site of the bore at Washing Bay and of examining the cores.

He asked the Author whether the kaolin in the Lough Neagh Clays was in the same coarsely crystalline condition as that in the lithomarge of the Postbasaltic zone of weathering, from which it was suggested that the materials of the clays had been derived.

Mr. R. B. Newton mentioned that, in 1911, he had examined a fragmentary gasteropod associated with dicotyledonous leaves (*Platanus*, etc.) contained in a ferruginous nodule belonging to the Interbasaltic beds of North-Eastern Ireland, found by Mr. R. Clark at Sands Bay, Lough Neagh, which resembled a form of *Viviparus* (= *Paludina*) related to *V. lentus* var. B of John Morris, from the British Lower Eocene (Woolwich & Reading Beds), which also occurs with similar leaf-impressions.[1]

Later on, Mr. Stelfox forwarded to the speaker some further molluscan fragments obtained by the present Author from a

[1] See G. A. J. Cole, 'The Interbasaltic Rocks of North-East Ireland' Mem. Geol. Surv. Ireland, 1912, p. 124.

boring in the Lough Neagh Clays; these consisted of a rather similar *Viviparus*, and an operculum of probably that genus, together with some Unioniform remains related to S. V. Wood's *Unio michaudi (?) non* Deshayes, from the Woolwich & Reading Beds.

These results would tend to support Mr. J. Starkie Gardner's opinion as to the older Eocene age of the Interbasaltic formation of North-Eastern Ireland. At the same time, it is suggested that the Irish deposits may be analogous to the intertrappean beds of the Deccan Trap Series of India and some similarly constituted beds of South Africa, which contain a lacustrine or fluviatile fauna and flora, and have been regarded as Uppermost Cretaceous. The interest of this supposed older age for the Lough Neagh Clays is somewhat emphasized by the fact that, among the plant-remains found in those beds, the Author has mentioned the occurrence of the Cretaceous genus *Dewalquea*.

Prof. P. G. H. Boswell noted with much interest the lithological and other similarities of the deposits to those occupying the basins of Bovey and Petrockstow in Devon, of Aquitanian age. The method of dealing with the plant-remains might be applied with success to the fragmentary lignitic material in the Petrockstow clays. The paper illustrated one of many instances of valuable scientific results being the outcome of explorations in connexion with the development of mineral resources, carried out by the late Ministry of Munitions. Geologists might well be grateful, both to the Ministry for the manner in which the work was prosecuted, and to the Author for his excellent supervision of the operations and description of the results.

Mr. H. W. Monckton remarked that the clays described reminded him of the Bovey Tracey beds, the age of which had also been a matter of much discussion. The record of *Dewalquea* did suggest Cretaceous in the present case; but, if the clays be of that age, so must be the underlying volcanic beds, and, from what the speaker knew of the volcanic series of Western Scotland, he doubted this result. He wished to join in congratulating the Author on a most interesting communication.

Mr. K. A. Knight Hallowes congratulated the Author on his paper, and said that it was of great interest in revealing a remarkable similarity between the basalts of the Loch Neagh area and the Deccan Trap Series of the Hyderabad State (Southern India), which he, as a member of the Geological Survey of India, had mapped geologically during the field-season 1922–23. The Author had remarked that the basalts of his area were either of Upper Cretaceous or of Lower Tertiary age, but that, until further evidence was forthcoming, he was unable definitely to say which. In the case of the similar basalts of Hyderabad, the intertrappeans, which correspond to the Interbasaltic horizons of the Author, contain a large number of freshwater Unionidæ; some of these have been identified by Dr. Prashad (of the Indian Museum, Calcutta). They show that the basalts of Hyderabad are more

likely to be of Lower Tertiary than of Upper Cretaceous age, and so it may be with the Lough Neagh basalts. In conclusion, he asked the Author whether his Interbasaltic horizons are in part composed of red bole, such as had occasionally been found forming the intertrappean horizons of Hyderabad.

Sir Arthur Smith Woodward referred to the interest and comparative precision of the modern methods of studying fossil plants. He was glad to inform the Fellows present that Prof. Johnson was about to re-examine the Starkie Gardner Collection from the Interbasaltic deposits of Antrim, now in the British Museum, with all the latest resources of palæobotanical technique. He anticipated valuable results from this research.

Prof. A. Hubert Cox enquired whether the possibility of a distant source of origin for the sediments had been considered. During early Tertiary time there appears to have been a regional tendency towards the production of pale clays, which were found at such widely different localities as Lough Neagh, Bovey Tracey, and at various levels in the Tertiary of the London Basin. Their deposition, therefore, seems to have been quite independent of the character of the underlying rocks. The Bovey deposits and some of those in the London Basin have been ascribed to eastward transport of material from the West of England granites. He asked, therefore, whether material from some distant granitic country could have contributed to the formation of the Lough Neagh clays.

Prof. H. L. Hawkins commented on the absence of evidence as to the history of the Lough Neagh Basin between the Lower Tertiary deposits now described and the formation of the present lake.

The Chairman (Prof. W. W. Watts) directed attention to the apparent conflict of zoological and botanical evidence. The late basic eruptions in many countries had been placed originally in the Cretaceous Period, but one by one they had proved to be Tertiary, and he was interested to hear that Mr. Hallowes deprecated dogmatism with reference to the Deccan Traps. He believed that the Antrim lavas had never before been penetrated by the drill, and the various stages of weathering were interesting, especially that between the upper and the lower basalts, at which horizon there was evidence of rhyolites, as at Tardree. The speaker alluded to the possibility that the remarkable deposits of lacustrine clays, scattered over the country from Lough Neagh to Bovey Tracey and from the Pennines to Petrockstow, might all be included in the Miocene Period.

The Author, in reply, made reference to the difficulties, touched on by Major Dwerryhouse, which were experienced in putting down the bore through the clays and lavas, and said that (as the boring was never likely to be repeated) he had secured the whole core, which was preserved in the cellars of the Geological Survey of Ireland, and was available for future research. He had not carried out any investigation of the grade of kaolin which made up the bulk of the clays, but that in the lithomarges was partly of fine

grain and partly coarser. None of it, however, seemed to be in so finely divided a state as the iron.

In reply to Mr. R. B. Newton, he said that he did not claim to have arrived at any such exact determination of the age of the series as would enable him to say whether they were to be referred to the Late Cretaceous or to the Early Tertiary. The three species of *Dewalquea* found were all new. Mr. Hallowes's statement that the Geological Survey of India was tending to the conclusion that part at least of the Deccan Traps were of Early Tertiary age might explain the apparent divergence between the views taken by Mr. Newton and Prof. Johnson. Bole-beds formed as marked a feature of the basalts of Antrim and the West of Scotland as they did of the Deccan Traps.

The point raised by Prof. Cox regarding the possible derivation of the sediments from a distant source was, to a great extent, dealt with in the body of the paper. The abundance of quartz-sand shows that the tributary streams certainly extended beyond the basalt plateau, but the titanium-dioxide content of the clays proves their derivation in the main from the Postbasaltic lithomarge.

20. *The* Old Red Sandstone *of the* Cardiff District.

By Albert Heard, M.Sc., Ph.D., F.G.S., and Richard Davies, M.Sc.[1] (Read March 12th, 1924.)

Contents.

I. Introduction.

The district which forms the subject of this communication is situate immediately north of Cardiff. It is bounded on the east and west by the Rhymney and Taff Valleys, and on the north by the Carboniferous rocks of the South Wales Coalfield. The area thus defined is about 16 square miles in extent.

We began a systematic petrological investigation of the Old Red Sandstone of this district in the hope that a more detailed knowledge of the sediments would establish a clearer conception of the conditions of deposition, of the probable source of the rocks, and of their relation to the underlying and overlying stratigraphical divisions. During the course of the work certain fossil localities were discovered. These represent the first records of Old Red Sandstone fossils within the area defined above.

The Old Red Sandstone of South Wales, which crops out round the greater part of the South Wales Coalfield, is a continuation of the Herefordshire outcrop; but, in the neighbourhood of Cardiff, it differs considerably in thickness from many other parts of the Old Red Sandstone around the Coalfield Syncline, and more especially from that of the North Crop.

There is a general lithological resemblance between the Old Red

[1] In the absence of Mr. Davies on geological work in Persia, the whole of this paper has been written by Dr. Heard.

Sandstone rocks of the Cardiff district and those of the North Crop, although there are certain differences at particular horizons (see p. 496).

Prof. W. J. Sollas[1] estimated the total thickness of the Old Red Sandstone of the Cardiff area to be 4273 feet, making his measurements along a line parallel to the Rhymney Railway, from the Silurian rocks at Roath Park to the base of the Carboniferous Limestone at Cefn On. At a later date, Sir Aubrey Strahan[2] estimated the thickness along this line at 3500 feet, comprising 2800 feet of Red Marls, 500 feet of Brownstones, and 200 feet of quartz-conglomerates and overlying sandstones and marls.

The higher beds, including the quartz-conglomerates with the underlying Brownstones, exercise a marked influence on the topography of the district, generally forming a bold scarp which looks southwards towards Cardiff. The underlying Red Marl Group forms a plain, which falls gradually towards Cardiff.[3] Across this plain run numerous ridges, which are approximately parallel with the strike of the Old Red Sandstone. Certain of these ridges represent outcrops of sandstone- and conglomerate-bands in the Red Marl Group.

Glacial deposits have undoubtedly modified the relief of this area, the greater part of which is drift-covered. In several places the drift has been observed, banked against both dip- and scarp-slopes of the ridges mentioned above. Other ridges probably represent moraines.

During the progress of this investigation, extensive building, sewerage works, and reservoir construction have proved of considerable value in exposing rocks in areas where there are few natural exposures.

II. THE COED-Y-COEDCAE FISH-BAND.

The fish-band, which has been newly discovered in the Red Marl Group of the Cardiff District, is exposed in the banks of the stream running through Coed-y-Coedcae.[4] The bed is about 2 feet thick, and consists of fragments of fish-remains, embedded in a conglomerate the petrology of which is described later (p. 503). Downwards, the conglomerate passes, by a complete but rapid transition, through a pebbly limestone, into a relatively pure limestone (see chemical analysis I, p. 505). Upwards, there is a similar transition, from conglomerate to a characteristic cornstone.

Unfortunately, only two exposures of this fish-band have been observed, occurring within 20 yards of each other, where the stream winds along the strike. On account of the widespread

[1] Q. J. G. S. vol. xxxv (1879) p. 475.

[2] 'Geology of the South Wales Coalfield: the Country around Newport' Mem. Geol. Surv. 1st ed. (1899) p. 16, and 2nd ed. (1909) p. 13.

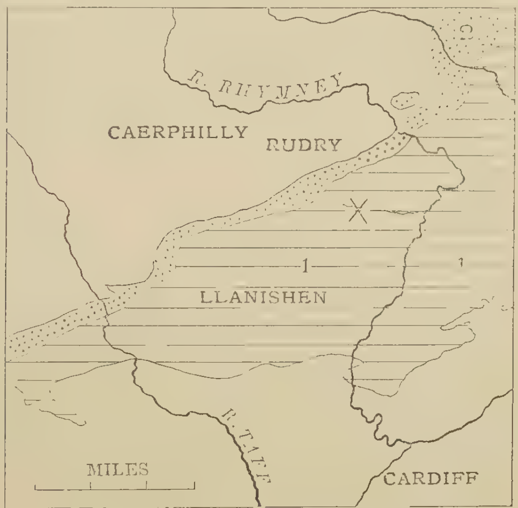
[3] A. H. Cox, 'Geology of the Cardiff District' Proc. Geol. Assoc. vol. xxxi (1920) p. 13.

[4] Geol. Surv. 6-inch Map, Glamorgan, xxxvii N.E.

occurrence of drift over this particular horizon of the Red Marl Group, it is improbable that further natural exposures will be discovered. The rock of the eastern exposure is relatively fresh; but the rock of the western exposure is badly weathered, and presents a characteristic brownish-black coloration in the field, the blackness being due to the matrix, which contains much calcium-phosphate. The weathered rock has a peculiar greasy feel.

The remains in the fish-bed include fragments of Pteraspidian and Cephalaspidian fishes, together with *Pachytheca*, and obscure plant-remains.

Fig. 1.—*Sketch-map of the Cardiff district, showing the outcrop of the Coed-y-Coedcae Fish-Band, on the scale of 4 miles to the inch, or 1 : 253,440.*



[1 = Outcrop of the Red Marl Group. 2 = Outcrop of the Middle and Upper Groups. X = Coed-y-Coedcae Fish-Band.]

(*a*) *Pteraspis.*

Many of the remains consist of the detached and broken fragments of the scutes of Pteraspidian types, some of which are preserved in a peculiar manner, which merits some further description. These are so abundant, that almost every example of the conglomerate, under the hammer, exhibits numerous irregular and more or less rounded patches. Each of these patches consists of an aggregate of polygonal cavities, preserved in either a bluish-green or a brownish-black substance, which a chemical analysis proves to be almost pure calcium-phosphate. These polygonal cavities, which are generally five- or six-sided, are approximately of uniform size in any one specimen, although the sizes vary slightly

in different specimens. The average diameter of each cell is about 0·16 mm. A detailed examination of the conglomerate reveals many well-preserved fragments, which facilitate a more thorough investigation. These fragments, even to the naked eye, are seen to consist of three different layers. The lowest or inner layer consists of a series of thin horizontal laminæ, which have a characteristic nacreous lustre. This nacreous layer is followed by a cancellated layer of polygonal cells. The septa which form the walls of these cells are normal to the nacreous layer, and in many specimens these septa apparently bend over and cap the cavities.[1] The septa consist of a granular calcium-phosphate. The cavities are usually empty. Following the cancellated layer is the outer or striated layer, which is generally preserved in the form of impressions, and consists of a series of small regular ridges and grooves. The striæ are parallel, and are generally straight, although in some cases there is a suggestion of concentric structure.

The view that these fragments represent Pteraspidian remains is confirmed by Sir Arthur Smith Woodward, who has kindly examined typical specimens from this fish-band; he writes that:— 'The bits of cancellated tissue are Pteraspidian, and seem to belong to *Pteraspis* itself.'

(*b*) *Cephalaspis.*

Sir Arthur Smith Woodward has identified other fragments as being probably portions of *Cephalaspis*. Fragments of the outer rim of the shield and well-marked Cephalaspidian scales occur, in addition to many fragments of the scute, some of which apparently represent portions of the cornua.

The proportion of Cephalaspidian to Pteraspidian remains in the Coed-y-Coedcae Fish-Band is about 1 : 4.

(*c*) *Pachytheca.*

White spherical bodies, measuring about 3·5 mm. in diameter, occur sparingly throughout the fish-band. They are preserved in calcium-carbonate, and, when broken, they present to the naked eye two distinct zones, an outer white 'cortex' and an inner darker zone. Sir Arthur Smith Woodward, to whom specimens were submitted for identification, informs us that Mr. W. N. Edwards considers that these specimens are probably *Pachytheca*. Several fruitless attempts have been made to obtain thin sections of this fossil. Ground surfaces have been prepared with difficulty, and these viewed under the microscope in incident light, exhibit not only the 'cortex' and inner zone, but also what are apparently the straight radiating filaments of the 'cortex.' None of the oval

[1] See E. Ray Lankester, 'Fishes of the Old Red Sandstone' Monogr. Palæont. Soc. vol. xxi, pt. i (1868) pp. 10 & 11.

bodies, described by Mr. C. A. Barber[1] as sometimes occurring between the inner and the outer zones, have been observed.

Pachytheca had previously been recorded from the Silurian of the Cardiff district,[2] but not from the Old Red Sandstone.

It is beyond the scope of this paper to discuss the affinities of *Pachytheca*; but it is interesting to note that it occurs in pyritized form, intimately associated with plants of early Devonian type, in the Senni Beds of the Brecon District.[3]

(*d*) Plant-Remains.

In addition to the fossils described above, fragments of carbonaceous material occur, which are probably plant-remains, but they are far too obscure to admit of even an approximate determination.

It has been indicated above that there is no available field evidence to prove that this *Pteraspis-Cephalaspis* Bed continues laterally to any extent. It is interesting to note that *Pteraspis, Cephalaspis*, and *Psammosteus*, together with comminuted vegetable remains, have been obtained from localities around Newport[4] outside the area under consideration. It is possible that these remains occur at the same horizon in the Red Marl Group as those of the Coed-y-Coedcae Fish-Band. However, the presence of Pteraspidian and Cephalaspidian remains establishes a definite Dittonian phase[5] for that part of the Red Marl Group which lies above and includes the fish-bed.

III. General Lithology of the Sediments.

The three subdivisions of the Old Red Sandstone in the Cardiff district[6] consist of:—

(A) Upper Group. Quartz - Conglomerate Group (about 200 feet thick).	(*a*) Upper portion of sandstones with some marls. (*b*) Lower portion: Lenticular quartz-conglomerate-beds, with sandstones, grits, and quartzites.

[1] Ann. Bot. vol. iii; no. 10 (1889–90) p. 144.

[2] J. Storrie, 'On the Occurrence of *Pachytheca* at Tymawr Quarry, Rumney' Rep. Brit. Assoc. (Cardiff) 1891, p. 652.

[3] It is proposed to describe the occurrence of these plants in a future communication by Prof. A. H. Cox and one of us (A. H.).

[4] 'Geology of the South Wales Coalfield: The Geology of the Country around Newport' Mem. Geol. Surv. 1899, p. 20.

[5] W. Wickham King, 'The Plexography of South Staffordshire' Trans. Inst. Min. Eng. vol. lxi (1921) p. 151.

[6] Sir Aubrey Strahan (Mem. Geol. Surv. 1899, p. 16) drew attention to the fact that, in making this threefold division, he did not suggest a precise correlation with the Upper, Middle, and Lower Old Red Sandstone of other parts of the British Isles.

(B) Middle Group. Brownstone Group (about 500 feet thick).	Highly micaceous reddish sandstones, grits, and flags, with some marls and pebble-beds.
(C) Lower Group. Red Marl Group (about 2800 feet thick).	Red - green and mottled marls, alternating with bands of red sandstone, some pale-green and yellow sandstone, red and grey cornstones, and numerous pebble-beds. Fragments of Cephalaspidian and Pteraspidian fishes are abundant at Coed-y-Coedcae.

(A) The Upper Group.

The Upper Group may be divided broadly into an upper and a lower part. The upper portion consists mainly of bands of sandstones, frequently pebbly, with alternations of marls, in which calcareous concretions are common. Towards the top of the upper portion, yellow sandstones and flags appear, although these are still accompanied by occasional red sandstones and by red and yellow marls.

No one locality gives a complete section from Old Red Sandstone to Carboniferous Limestone; but, by combining observations at a number of localities, it is found that there is no stratigraphical break between these two rock series. On the contrary, there appears to be an upward transition from red and yellow sandstones, through red sands and calcareous shales, to the mottled limestone at the base of the Carboniferous.

The lower part of the Upper Group consists of the massive quartz-conglomerates, with coarse grits and some quartzites. The bands of quartz-conglomerate, although apparently at a constant horizon, are lenticular in character, and do not persist laterally for any great distance. Individual bands appear not to exceed 30 to 40 feet in thickness. There seems to be a progressive diminution in the size of the pebbles towards the thin ends of the lenticles, until finally each band passes laterally into a coarse grit or a quartzite. Bands of quartzite, sometimes pink in colour, are associated with the quartz-conglomerates, but are of more general occurrence just below the conglomerates.

(B) The Brownstone Group.

This series generally forms the scarp-slope of the bold ridge which overlooks Cardiff. The Brownstones consist of highly micaceous reddish sandstones, grits, and flags, with some interbedded red marls.

Immediately below the quartz-conglomerates, bands of quartzite alternate with red marls and sandstone. The secondary silicification of these bands is well exhibited (for instance, in the roadside west of Craig Llysfaen); in many cases the paths of the siliceous

solutions can be traced along cracks and joints, on each side of which the beds have been silicified and turned into quartzites.

Pebble-beds occur in the Brownstone Group, but do not attain an importance comparable with the pebble-beds in the Red Marl Group below.

(C) The Red Marl Group.

This group consists of red and mottled marls, alternating with numerous bands of highly micaceous sandstones, pebble-beds, and cornstones. The marls are generally very micaceous, and frequently contain isolated pebbles and concretions. The sandstone-beds vary in thickness, from 1 or 2 inches to about 6 feet, and exhibit a greater variation in colour and texture than those of the Brownstones. Although they are generally red to brownish-red in colour, a few pale green and yellow bands occur above the Coed-y-Coedcae Fish-Band.

Every gradation of sedimentary rock-types exists in the Red Marl Group, from pebble-beds and coarse sandstones, through gritty marls and impure cornstones, to relatively pure limestones.

Some of the pebble-beds apparently persist laterally over distances of at least several miles. Practically all the pebbles in these beds consist of a medium to fine-grained sandstone; some of these pebbles have a rather characteristic shape, being four-sided, with a triangular base and three more or less triangular facets on the top; in fact, these facetted pebbles, which attain a maximum length of 6 inches, bear a strong resemblance to dreikanters. The edges, however, are slightly rounded, and present a waterworn appearance. These peculiar and characteristic forms probably represent incompletely rounded fragments, which were originally broken from a well-jointed rock.

The new reservoir, which is being constructed near Rhiwbina, 5 miles north of Cardiff, is immediately on the outcrop of one of the most characteristic pebble-bands in the Red Marl Group, and affords excellent opportunities for detailed investigation. The beds are apparently at the same horizon as the pebble-bed at the entrance to the Cefn-On Tunnel, 2 miles farther east,[1] and consist of a series of pebble-bands, alternating with laminated marls. The marls are usually red, but are frequently mottled with green, and they present a striking resemblance to the Keuper Marls of the Penarth cliffs.

The pebble-beds are not laminated, and the pebbles are generally distributed erratically in the beds; they are not arranged parallel to the bedding-plane, except at the base of each band, each pebble being embedded in a thick envelope of the sandy matrix. The interbedded marls are often slickensided, and frequently contain isolated pebbles up to 5 inches long.

[1] 'Geology of the South Wales Coalfield: The Geology of the Country around Newport' Mem. Geol. Surv. 1899, p. 14.

Along the banks of the stream running through Coed-y-Coedcae, the rocks are exposed for a distance of about half a mile, and this traverse has been mapped in detail. It shows a rapid alternation of sandstones, marls, and cornstones which are mainly conglomeratic. Some of the marls exhibit beautiful ripple-markings.

The fish-band, which is described above, has been observed only in the banks of this stream.

The base of the Red Marl Group, and its relation to the underlying Silurian rocks, will be discussed in a later section.

The Relation of the Red Marl Group to the Brownstone Group.

On the North Crop, the sage-green sandstones of the Senni Beds [1] form a conspicuous feature of the Brecon Beacons. These green sandstones are not to be identified in the Cardiff district, although a few thin bands of pale-green sandstones occur in the upper part of the Red Marl Group above the Coed-y-Coedcae Fish-Band.

It is possible that the sediments between the Fish-Band and the Brownstone Group represent the Senni Beds, as there is no evidence to suggest that the Senni Beds are not represented on the South Crop.

However, the presence of a few thin bands of green sandstone does not justify a further subdivision of the existing Red Marl Group of the Cardiff area.

The Division between the Upper and the Lower Old Red Sandstone.

No lithological evidence has been obtained, such as would justify the drawing of a line between the Upper and the Lower Old Red Sandstone at any particular horizon. In fact, we believe that the Middle Old Red Sandstone may quite conceivably be represented in the Cardiff district.

IV. Petrology of the Old Red Sandstone

(1) Methods of Investigation.

The constituents of the sediments range from pebbles 6 inches long to the very fine material which forms the greater part of the marls. Numerous pebbles, from the various pebble-beds and conglomerates, have been examined under the microscope, and many thin sections of sandstones from various horizons have been prepared.

The usual methods of determining the mineralogical composition of sediments have been employed where possible. The three

[1] 'The Geology of the Country around Ammanford' Mem. Geol. Surv. 1907, p. 54.

groups of the Old Red Sandstone were sampled laterally and vertically, as exhaustively as exposures permitted. The samples were carefully crushed, panned, and sifted, sieves of 30, 60, and 90-mesh to the inch being used. By far the greater proportion of the heavy minerals passed the 90-mesh. The dust was removed by lixiviation and decantation. When it was considered necessary, portions of the samples were treated with dilute hydrochloric acid.

In the isolation of the various mineral constituents by means of liquids of known density, the following were employed: Bromoform of specific gravity 2·85, Sonstadt's solution of varying densities, also occasionally silver nitrate. The use of a hand-magnet, and of an electro-magnet with adjustable pole-pieces, facilitated the identification of many minerals. Chemical and microchemical methods have been frequently used to confirm microscopic determinations; and the method of identification of mineral grains by means of a dark background and oblique illumination [1] has been utilized with some success. The heavy residues were generally divided into three portions: one was mounted immediately; one, if necessary, after treatment with hydrochloric acid; and the third was retained for reference and chemical tests.

On the whole, the three groups of the Old Red Sandstone, with the exception of the marls and the cornstones, exhibited some, though not by any means a complete, uniformity in mineralogical composition.

(2) The Quartz-Conglomerate and Sandstone Group.

(*a*) The Pebbles in the Quartz-Conglomerates.

The quartz-conglomerates consist essentially of well-rounded white and bluish (opalescent) quartz-pebbles in a siliceous matrix. The pebbles almost invariably exhibit a very strained polarization, with accompanying crenulate and mylonitic structure. Quartz-pebbles without inclusions are extremely rare: inclusions are frequently present in such quantities, and so densely aggregated, as to give a cloudy appearance to the pebble.

The inclusions are of some significance, in view of the fact that Dr. W. Mackie [2] has suggested that an examination of the inclusions in quartz enables the rock-type from which the grains have been derived to be deduced.

Relatively large solid inclusions, both idiomorphic and rounded, are extraordinarily abundant in the quartz-pebbles, and a preponderance of such regular inclusions, according to Dr. Mackie, suggests an origin from metamorphic rocks. Among these regular inclusions, zircon and tourmaline are of common occurrence, generally presenting well-rounded forms, although idiomorphic forms have been observed. Green tourmaline often occurs in a rather peculiar manner, being present as inclusions which frequently

[1] R. H. Rastall, Geol. Mag. vol. lx (1923) p. 35.
[2] Trans. Edin. Geol. Soc. vol. vii (1897) p. 143.

form curved and S-shaped lines in the quartz. These tourmaline inclusions are pleochroic, and exhibit both triangular and hexagonal basal sections. It should be noted that the pebbles containing these inclusions of tourmaline are, as a rule, relatively free from the undulose extinction so characteristic of most of the quartz-pebbles.

Inclusions of rutile are present, and are generally rounded and deep amber in colour. Irregular iron-ores, mainly magnetite, are common as inclusions. Gaseous and liquid inclusions are common; and negative crystals, with perfect hexagonal outline, have been observed. Minute rounded and indeterminate inclusions occur in streams, which often cross at angles of 60°.[1]

In addition to pebbles of quartz-gneisses and quartz-schists, pebbles of a fine-grained sericite-schist have been noted; occasionally, pebbles of a medium-grained and also of a fine-grained sandstone are encountered. These sandstone-pebbles are so intensely iron-stained that, in thin section, only subangular quartz and white mica can be identified. Although they yield so little information under the microscope, the coarser types bear some resemblance to the sandstone-pebbles in the pebble-beds of the Red Marl Group, which are described later (p. 503).

Pebbles of jaspers and cherts are abundant in the quartz-conglomerates. The jaspers are usually subangular in shape, contrasting strongly with the well-rounded quartz-pebbles: they are generally brick-red, although brown to green varieties also occur. Under the microscope these jaspers often reveal minute felspar-laths in a cryptocrystalline matrix, and thus suggest a possible derivation from a felsite. One specimen has been observed that might possibly have been derived from a perlitic pitchstone. Many of these jasper (felsite) pebbles contain more or less circular cavities filled with secondary silica: the jaspers are frequently traversed by thin quartz-veins, often arranged in parallel series.

Both microcrystalline and cryptocrystalline cherts occur. They are generally well-rounded, and no suggestion of organic remains has been noted. These cherts are usually found among the smaller constituents of the quartz-conglomerates. Relatively fresh oligoclase-andesine is also present as rounded fragments.

(*b*) The Sandstones above the Quartz-Conglomerates.

The sandstones vary from coarse to fine-grained rocks, and under the microscope are seen to be composed mainly of subangular quartz-grains. Some of the angular quartz-grains possibly owe their angularity to a secondary deposition of silica.

A characteristic feature of these sandstones is the presence of perfectly fresh microcline, which occurs in well-rounded grains. Oligoclase to oligoclase-andesine felspars are also common; these plagioclases are remarkably fresh. Potash-felspars appear to be

[1] See A. Gilligan, 'Petrography of the Millstone Grit of Yorkshire' Q. J. G. S. vol. lxxv (1919) p. 254.

represented by certain badly-weathered aggregates with innumerable sericite-laths. White mica, in laths which are frequently bent, is abundant. Large flakes of chlorite are also present, and zircons and apatite have been observed. These sandstones, therefore, approach arkoses in composition.

(c) The Finer Constituents of the Upper Group.

The coarse conglomerates contain but few heavy minerals in the matrix; but, where the conglomerates become more finely granular, the mineral assemblage is so similar to that of the overlying sandstones and grits that both will be dealt with together. Exposures of beds belonging to this group are numerous, and have afforded opportunities of exhaustive sampling, both laterally and vertically: the examination of the finer constituents revealed a collection of minerals which, on the whole, is remarkably constant and uniform throughout. The Upper Group of the Old Red Sandstone is characterized by abundant zircon, rutile, tourmaline, and ilmenite, with apatite, garnet, and pyrites. Felspars occur throughout.

Quartz.—The quartz in the finer sediments is similar to that described above, although large regular inclusions are less common, and the evidence of acute straining is perhaps less conspicuous. The greater proportion of the grains is angular to subangular. Occasionally, perfectly rounded grains are present, but they do not appear to be characteristic of any particular horizon.

Felspars.—Microcline is relatively common, occurring in fresh rounded grains. The cross-hatching is beautifully exhibited in most of the specimens. Oligoclase and oligoclase-andesine crystals are common, and they generally are remarkably fresh; they occur in rounded elongated forms, and are invariably much narrower than the microcline-grains. The freshness of these soda-lime plagioclases is suggestive, and will be discussed later.

Weathered aggregates, containing numerous sericite-laths, often with a parallel arrangement, suggest a derivation from a potash-felspar. No potash-felspar, fresh enough to be detected with certainty, has, however, been observed.

Chert.—Chert occurs throughout as well-rounded fragments. No traces of organic structures have been observed. The cherts which are present as micro- and cryptocrystalline fragments are usually well rounded, even when most of the quartz-grains in the same specimen are conspicuously angular.

Mica.—White mica is very abundant, in the form of large irregular flakes, and is distributed freely throughout both light and heavy crops. Inclusions are numerous, and range from densely packed dust-inclusions, which give the mica a cloudy appearance, to well-developed regular inclusions of zircon, rutile, rutile-needles, and magnetite. Several flakes of mica, with beautifully developed sagenitic rutile, have been observed. Most of the flakes of mica exhibit evidence of strain in their marked undulose extinction.

Zircon is extremely abundant in every sample examined. In

many cases, particularly in the fine-grained sediments, it forms the greater part of the heavy crop.

The zircons exhibit great diversity of size, form, and colour: both well-rounded and idiomorphic grains are abundant.

Two distinct types are present:—(*a*) Clear, colourless, and relatively small grains of which the larger proportion is idiomorphic; (*b*) faintly-coloured types, which range from a pinkish-yellow (often with a purplish tinge) to almost opaque grains. This latter type is generally well-rounded, and oval forms are common. A short prismatic habit is characteristic of these coloured zircons, as is also a well-marked zoning. Often the zircons are fractured, the cracks running apparently parallel to the 111 pyramid.

Among the colourless types, many beautiful examples of 'parallel growth' have been noted, and occasionally specimens have been observed where both individuals are well-rounded. Dr. R. H. Rastall & Mr. W. H. Wilcockson[1] figure similar occurrences from the Lake District. Among the numerous types of inclusions in the zircons, the following occur: gaseous, vitreous, and tubular inclusions, together with negative and solid inclusions, among which perfect minute crystals of zircon are common.

The following forms have been noted among the idiomorphic zircons: first and second-order prisms, pyramids 111 and 311, and occasionally the 001 plane is present capping the 111 pyramid.

The significance of the large proportion of faintly-coloured and well-rounded zircons to the colourless types will be discussed later.

Rutile is always subordinate in amount to zircon, and specimens showing complete crystal form are rare. Prism-faces with rounded pyramidal terminations occur. Short prisms with irregular terminations are common, and apparently represent fractured crystals; but the mineral generally is present in sub-rounded and oval grains. It presents a wide variation in colour, from a pale yellow to an intense deep amber. Geniculate twins have been observed, but are very rare; on the other hand, many polysynthetic twins have been noted, and in one case alone an octet twin has been observed. Inclusions occur, but are uncommon; zircon has been noted among them. Apart from a few minute spear-shaped crystals intimately associated with leucoxene, the rutile with its well-rolled prisms is apparently allothigenic.

Tourmaline is a common constituent of this division, occurring generally as irregular, angular, and sub-rounded fragments, and less frequently as fractured and slightly-rounded prisms. Perfectly rounded grains are also of common occurrence. Most of the tourmaline-fragments are brown, with a definite purplish tinge, and are intensely pleochroic. Inclusions are numerous, including vitreous and solid inclusions, while cores of fine dust-aggregates are common.

Blue tourmaline also occurs sparingly, mainly in the form of angular and subangular irregular grains; it exhibits very little

[1] 'Accessory Minerals of the Lake District Granites' Q. J. G. S. vol. lxxi (1915–17) p. 612.

pleochroism. Yellowish-green and practically colourless types also are observed.

Garnet.—Although garnets are common in the Upper Group, they are not abundant when compared with the number of garnets present in the Red Marl Group. Pink and colourless varieties occur, and frequently present angular and subangular forms with re-entrant angles. Presumably these forms owe their irregular jagged outline to the dodecahedral cleavage of the grains, which, however, is only occasionally well marked in the garnets of this division. In addition to these more or less angular types, well-rounded and almost spherical grains occur. On the whole, the garnets of this division are relatively smaller than those of the Red Marl Group. The two types will be compared and contrasted below (p. 507).

Apatite is abundant, occurring generally as large well-rounded grains, and less frequently as rudely prismatic forms, although in a few cases almost perfect prisms, with low pyramidal terminations, have been noted. Many of the grains contain cores which are either opaque or, more commonly, brown and pleochroic. These cores vary greatly in size: sometimes the whole of the crystal is cloudy and almost opaque.

Ilmenite is the most abundant iron-ore, and occurs in irregular forms, intimately associated with greyish-white leucoxene, which is often stained brown. In some cases, minute outgrowths of spear-shaped rutile, and of a faint yellowish crystal which is possibly anatase, have been observed.

Pyrites is abundant, being present in well-rounded grains (? marcasite), and sometimes in minute forms which suggest slightly-rounded cubes. It exhibits a variety of colours in incident light. Its presence has been verified by means of electromagnetic and chemical tests.

Magnetite occurs sparingly; it is generally present as inclusions in other minerals.

Fluorspar has been observed at only one horizon in the Upper Group, on the crest of the anticline, north of Craig Llysfaen. It exists in the form of large triangular cleavage-flakes. Fluorspar also occurs farther east, on the crest of the same anticline in the Brownstone Group; it is probably authigenic.

(3) The Brownstone Group.

As in the case of the Upper Group, chert, microcline, and oligoclase-andesine occur throughout, and are apparently similar in the proportion present and the more or less even distribution. The heavy minerals of this group, however, differ considerably in the relative proportion present, as compared with those of the overlying group. Garnets, zircons, and iron-ores are abundant, and form the greater part of most of the heavy crops.

There is a definite and very appreciable increase in the amount of garnets present, and a corresponding decrease in the amounts of

tourmaline and rutile. No blue tourmaline has been observed. Chlorite appears in quantity in the Brownstone Group, and becomes a persistent mineral in every crop. Apatite is common throughout, while barytes is abundant at several horizons, and increases in amount towards the base: it is presumably authigenic, occurring as a cementing material. Among these minerals only the following call for any further description.

Garnet.—Both pink and colourless types occur. A noteworthy feature is the great development of what is presumably a dodecahedral cleavage. This parting has been observed in other rocks by several workers.[1] There is apparently a progressive increase in the development of this parting on passing from higher to lower horizons of the Brownstone Group. Although rounded forms are fairly common, the garnets are mainly angular, and present (in most cases) peculiar zigzag shapes, which are obviously determined by the dodecahedral parting.

Apatite occurs as well-rounded grains, rudely prismatic forms, and occasionally as well-developed prisms terminating in rounded pyramids. In this division of the Old Red Sandstone there is a larger proportion of grains exhibiting a tendency towards idiomorphism than is evident in the Upper Group. This feature becomes more evident towards the base of the Brownstone Group.

Chlorite, which is present in negligible amounts in the Upper Group, forms a most conspicuous feature of the heavier separations of the Brownstones. It occurs characteristically in the form of large, irregular, dark-green flakes, which are generally strained.

Anatase.—Minute crystals of this mineral, intimately associated with leucoxene, are fairly common, but only one perfectly idiomorphic crystal, steel-grey in colour, and of a tabular habit with low pyramids, has been observed in the whole of the Old Red Sandstone Series.

(4) The Red Marl Group.

The marls themselves reveal little of petrological interest on detailed examination. They consist mainly of ferruginous argillaceous silt, more or less calcareous, and contain varying amounts of minute and generally angular quartz-grains, and much white mica, with a little fairly fresh biotite.

On the other hand, the numerous pebble-beds, grits, and sandstones in the Red Marl Group present many features of interest. Numerous thin sections of the pebbles from the pebble-beds at different horizons, and of the many different grits and sandstones, have been prepared. The pebbles, with the exception of a few greatly sheared quartz-pebbles, consist entirely of a very characteristic fine-grained sandstone, which has not been localized. It

[1] T. O. Bosworth, 'On the Heavy Minerals in the Sandstones of the Scottish Carboniferous Rocks' Proc. Geol. Assoc. vol. xxiv (1913) p. 58; A. Gilligan, Q. J. G. S. vol. lxxv (1919) p. 265; R. H. Rastall & W. H. Wilcockson, *ibid.* vol. lxxi (1915–17) p. 612.

contains angular to sub-rounded quartz, large laths of muscovite frequently bent, much chlorite (some of which is vermicular), and a relatively large number of remarkably fresh plagioclases, in the neighbourhood of oligoclase-andesine. Many aggregates, often stained with chlorite, are present. These sandstones contain much ferruginous material, which at some localities (as, for example, at Lisvane) is present in such quantity that, with the exception of quartz and mica, the constituents are indeterminable. The few quartz-pebbles that are distributed sparingly throughout the pebble-bed consist of greatly sheared quartz, clouded with dust-inclusions. One peculiar quartz-pebble has been noted, covered with deep circular pittings measuring about 3 mm. in diameter; but, in thin section, this pebble exhibited the characteristic structure of a quartz-gneiss.

The fine conglomerate, associated with the fish-band, under the microscope is seen to consist of quartz-grains, with some zircon-inclusions, and numerous dust-inclusions, quartzite-pebbles, quartz-schists, much mylonitic quartz, and many twisted laths of discoloured mica. One quartzite-pebble containing an idiomorphic garnet has been observed. Rounded cherts are common. The matrix is proved by chemical analysis to consist largely of a ferruginous calcium-phosphate. Irregular shimmer-aggregates containing quartz-blebs have been observed. The heavy crop from this pebble-bed consists mainly of zircons, rutile, and a large proportion of garnets.

The sandstones of the Red Marl Group, in thin section, present little variation in composition, although they vary considerably in texture. They contain both well-rounded and subangular quartz, some microcline, relatively fresh oligoclase, and numerous alteration-aggregates. Twisted flakes of white mica and cherts are abundant. Chlorite in large flakes is a common constituent. Elongated fragments preserved in chalcedony, identical in shape and size with the 'woody' tracheids of *Psilophyton*, have been observed at different horizons.

The isolation of the constituents of the sandstones revealed a rich heavy mineral assemblage. The lighter crops contained mainly quartz, with the usual fresh plagioclases and much mica. These call for no further description.

In the heavy crops, zircon is very abundant, the faintly-coloured and clouded types being dominant; rutile and tourmaline are present in a markedly higher proportion than in the Brownstones. Apatite is very common, forming the greater part of many separations. It is relatively much larger, and has a greater tendency to present slightly-rounded idiomorphic forms, than that of the Middle and Upper Groups of the Old Red Sandstone. Garnets are much more abundant in the Red Marl Group, where most of the grains have a pronounced dodecahedral parting, with its characteristically associated zigzag angular shape. By far the greater proportion of the garnets is of a colourless variety, although pink garnets are not rare. Chlorite is extraordinarily abundant,

generally occurring in large green flakes, frequently strained; and barytes is abundant at many horizons. Magnetite occurs only as inclusions; ilmenite with leucoxene and especially pyrites are the commonest iron-ores.

(5) The Cornstones.

The cornstones, which form so characteristic a feature of the Red Marl Group, occur in relatively thin bands when compared with those of the northern outcrop of the Old Red Sandstone of South Wales. The cornstones of the Cardiff district seldom exceed 2 or 3 feet in thickness; more frequently they form bands about 1 foot thick. Individual bands are lenticular, and do not appear to persist laterally over a wide area.

Great petrological variation is exhibited among the cornstones.[1] All types exist, from a relatively pure limestone, through conglomeratic cornstones, to extremely gritty impure types, which closely approach a marl in composition. There is also a great variation in colour, intensely red iron-stained, pink, grey, and dark-grey types occurring. Weathered specimens exhibit a nodular appearance.

Generally, the cornstones consist of well-rounded fragments of gritty marls, an extremely fine-grained, micaceous, calcareous sandstone, and 'amorphous' calcium carbonate, with numerous minute grains of angular quartz, much mica, and some chlorite. These rounded pebbles, which sometimes have calcite-filled cracks similar to those of septarian nodules, are usually embedded in a clear matrix of calcium carbonate: this latter often contains aggregates of minute angular quartz-fragments, with mica and chlorite. The minute angular grains of quartz form a very characteristic feature throughout, not only of the matrix, but also of most of the gritty calcareous pebbles.

The crystalline matrix, which occurs so persistently, represents recrystallized calcareous material; owing to the recrystallization, all the impurities (such as iron oxides and minute mineral grains) have either been pushed to the margins of the newly-formed crystal mosaics, or have formed aggregates in the middle of the mosaics.

Obscure fish-remains occur frequently (? Pteraspidian types) at many horizons, but they are especially abundant in the limestone below the Coed-y-Coedcae Fish-Band.

At many horizons there are numerous rounded bodies present, with badly preserved structures, which are not easily accounted for by surmising a purely inorganic origin. The state of the preservation varies with the amount of the recrystallization to which the rocks have been subjected. Where the rock has undergone great recrystallization, these rounded bodies only show as dark obscure patches; where recrystallization has not affected the whole of the matrix, but has driven the hydrated iron oxide against and into these bodies, suggestions of structures are still discernible.

[1] See chemical analyses below, p. 505.

The bodies, of an average diameter of 0·3 mm., have been observed in three types.

(a) Spiral forms, with septa (?) preserved in the outer whorl.

(b) Chambered forms, suggestive of *Globigerina*.

(c) Rounded and oval forms showing distinct central and outer zones (an inorganic origin might be postulated for this type).

We approach the suggestion of the presence of organic remains in the cornstones with caution; yet, in our opinion, many of these rounded bodies may represent the remains of foraminifera.

It has already been mentioned that relatively pure limestones occur sparingly, and the best example of this type of Red Marl Group limestone encountered in this investigation occurs immediately below the Fish-Band. It consists mainly of recrystallized calcium carbonate, and contains many irregular plates of calcite. Where two plates are in contact one with the other pressure-sutures or styolites[1] are well developed, similar to the pressure-sutures which occur between the crinoidal plates of many Carboniferous limestones. This type of limestone contains numerous irregular forms, which are very suggestive of the occurrence of algæ; recrystallization has obscured the forms, but structures which may represent algal tubules are present.

It is hoped that a further investigation of the cornstones, now in progress, will reveal more definite evidence of the presence of organic remains in the limestones of the Old Red Sandstone of the Cardiff district.

The following partial chemical analyses of cornstones illustrate the great variation in composition among the different types.

Partial Chemical Analyses of Typical Cornstones.[2]

			Siliceous material.	Fe & Al as carbonates.	$CaCO_3$.	$MgCO_3$.
I.	O.R.S.[3] C. 103.	Pure cornstone below the Fish-Band.	8·64	0·714	90·91	1·17
II.	O.R.S. C. 80.	Intensely red conglomeratic type.	36·5	6·09	48·80	1·17
III.	O.R.S. C. 105.	Pale-grey type.	26·3	1·20	56·80	5·22
IV.	O.R.S. C. 65.	Pink type.	27·5	2·68	63·10	5·10

[1] See A. E. Trueman, Proc. Geol. Assoc. vol. xxxiii (1922) p. 25.

[2] We are indebted to Prof. W. J. Jones, of the Chemical Department, University College, Cardiff, for these analyses.

[3] Reference-numbers of specimens in the collection of the Geological Department, University College, Cardiff.

When the cornstones are treated with hydrochloric acid to remove the carbonates, the residual silt is characterized by the presence of a larger proportion of the minute angular quartz-fragments, already noted as occurring in great quantities throughout most of the cornstones. Brown prismatic grains of tourmaline and white mica and chlorite are abundant; an interesting feature is the frequent occurrence of relatively fresh brown mica.

Origin of the Cornstones.

Prof. W. J. Sollas [1] has suggested that the cornstones of South Wales represent mechanically derived sediments. Prof. A. H. Cox [2] suggests that the cornstones 'probably owe their existence to direct precipitation.'

The segregation of the minute angular quartz-grains in the recrystallized portion of the cornstones, and their more or less even distribution throughout most of the constituents, including septarian nodules, suggest that originally these cornstones were calcareous silts, with the minute quartz-fragments and other detrital constituents distributed uniformly throughout. These silts must owe their origin, either to chemically or to organically precipitated lime, either to actual mechanical sedimentation or to a combination of these factors. A stream highly charged with suspended and dissolved lime would rapidly deposit its load on entering shallow brackish-water lagoons. Mechanical agitation and the presence of algæ would facilitate this deposition.

It is probable that the cornstones of South Wales, with their relatively high content of detrital material, represent a combination of mechanically and chemically formed sediments, deposited in brackish-water lagoons under rapidly changing conditions.

(6) Summary of the Petrology.

Realizing the great probability of variation in the local distribution of the constituents of shallow-water sediments, we have not attempted any detailed quantitative mineralogical analysis of the rocks under consideration; but we have contented ourselves with keeping a record of the approximately relative proportion of most of the constituents. In the case of the sandstones above the quartz-conglomerates of the Upper Group and of the coarser beds of the Red Marl Group, the constituents are remarkably evenly distributed throughout the rocks. The heavy minerals of the Brownstones are not distributed so uniformly, some few heavy crops containing nothing but a few zircons; the examination of a large number of samples has, however, enabled us to make an approximate determination.

[1] 'Silurian District of Rhymney & Penylan, Cardiff' Q. J. G. S. vol. xxxv (1879) p. 492.

[2] 'Geology of the Cardiff District' Proc. Geol. Assoc. vol. xxxi (1920) p. 13.

It will be noted that there is a variation in the relative amounts of the constituents present in each of the three groups of the Old Red Sandstone. Consequently, these sediments may be divided roughly into three zones, according to the most abundant heavy minerals present.

(*a*) Upper, with abundant zircon, rutile, tourmaline, and apatite;

(*b*) Middle, with abundant zircon, garnet, and chlorite;

(*c*) Lower, with abundant zircon, rutile, garnet, tourmaline, apatite, and chlorite.

These relations are expressed diagrammatically in fig. 2 (p. 508). The three mineralogical zones coincide, more or less, with the main stratigraphical groups.

However, too much emphasis cannot legitimately be laid on the variation at different horizons of such constituents as rutile, garnet, and apatite, when these results are applied to problems connected with the source, etc., of the sediments. Interstratal solutions have undoubtedly been great factors in the ultimate distribution and form of such constituents as apatite and garnet. It is significant to note that apatite is most abundant and fresh where there is a largely calcareous cement. Apatite is very abundant, and many large grains with a marked tendency towards idiomorphism are common in the Red Marl Group, where lime is a dominant factor in the cement. In the Upper Group of the Old Red Sandstone, the apatite is relatively small in size and generally well rounded; but it becomes more pronounced in the more calcareous sandstones which occur immediately below the Carboniferous Limestone. In the Brownstones, apatite is of small size, well rounded, and far less abundant; in these there is a much smaller amount of calcareous cementing-material. Apparently, the calcium carbonate prevents the phosphate from going into solution. Dr. Mackie[1] states that ferric hydrate acts as a preservative for apatite.

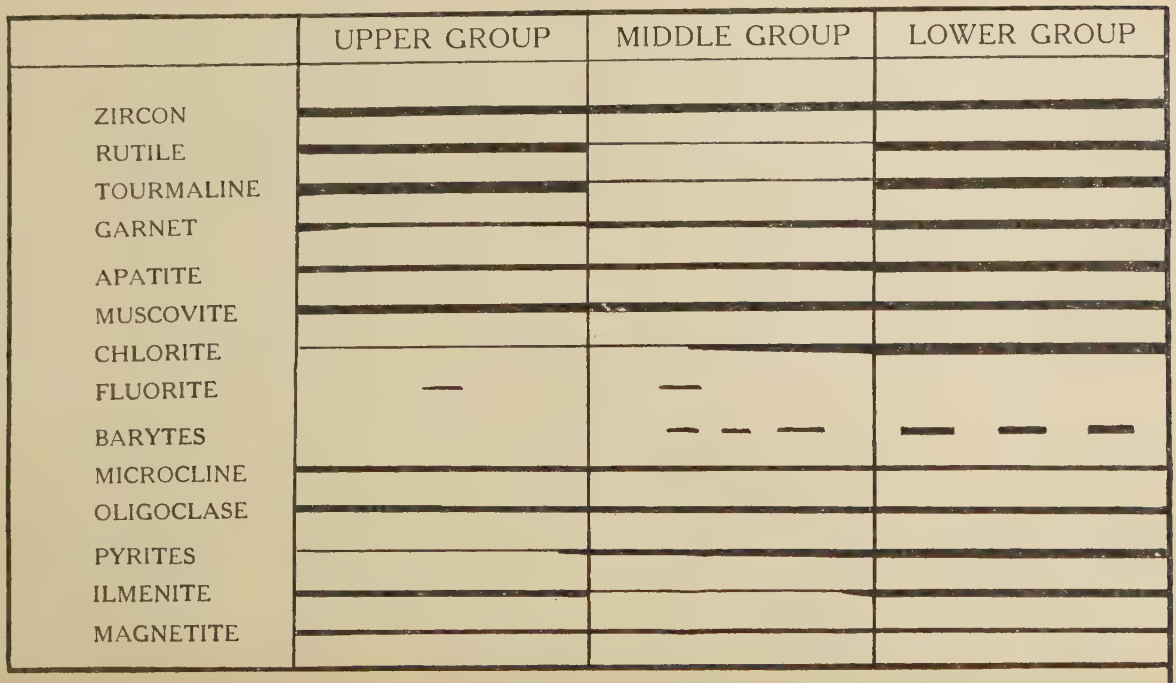
Similarly, the garnets of the Upper and Middle Groups show signs of a greater susceptibility to alteration in their smaller rounded forms and frequent cloudiness. In the Red Marl Group they are almost invariably clear, and larger and angular, with frequent etch-marks. Dr. Mackie (*loc. cit.*) states that:—

'Carbonate of lime preserves garnets, which, when extracted from sandstone highly charged with carbonate of lime, always appear with etched surfaces. It would appear that, so long as solutions charged with carbonate of lime circle round the garnets in the sediments, they probably tend to be dissolved, thus giving rise to etching of their surfaces. As soon, however, as calcite begins to be deposited around them in solid form, all solution ceases, but they retain their etched surfaces.'

An interesting point is the degree to which the rhombo-dodecahedral parting is developed at different horizons; there is apparently a transition from a much larger proportion of uncleaved crystals in the Upper Group, through a gradually increasing

[1] Trans. Edin. Geol. Soc. vol. xi, pt. 2 (1923) p. 149.

Fig. 2.—*Diagram showing the approximate proportions of the more important constituents of the Old Red Sandstone of the Cardiff district, excluding quartz and chert.*



quantity of cleaved types, at the expense of uncleaved grains, until down in the Red Marl Group practically every garnet has a well-developed parting.

Dr. T. O. Bosworth [1] suggests that the dodecahedral cleavage of the garnets in some sediments is induced during transportation by water. If this be assumed, it would appear probable that the greater development of the dodecahedral parting in the garnets found in the lower part of the Old Red Sandstone, as compared with those in the higher part, is due to a greater distance of transport. Further, it is possible that the proportion of cleaved garnets at any one horizon may furnish some measure of the distance from the original source of supply.

It has already been noted that there are two types of zircons present throughout the Old Red Sandstone. In addition to colourless zircons, relatively large quantities of a faint pinkish-brown type, sometimes with a slight purplish tinge, occur as stumpy, often well-rounded, and ovoid forms. This association of the two types of zircons, and more especially the relative proportions of each present, is interesting in view of the recent paper by Dr. W. Mackie,[2] who has found purple zircons in all sediments from pre-Torridonian to recent sands, and states that the original source of these zircons is the Lewisian Gneiss of the North of Scotland. He describes these 'purple' zircons as varying in colour from a faint purplish or pinkish tint to an intensity which renders the crystal nearly opaque. Presumably, the faintly coloured and almost opaque forms in the Old Red Sandstones of the Cardiff area are similar to Dr. Mackie's purple types, and the relatively large proportion of these to the colourless types suggests a direct derivation from gneissic rocks similar to the Lewisian Gneiss.

No sphene has been detected in the sediments, although it is generally a common associate of chlorite, which occurs so abundantly in the Middle and Lower Groups of the Old Red Sandstone. As we were aware of the difficulty usually experienced in detecting sphene in mineral residues, a careful watch has been maintained, but none has been observed. Dr. R. H. Rastall [3] notes the fact that rutile is abnormally abundant in most sediments, when the relatively small amount present in known igneous rocks is considered. He suggests that it may have arisen by the decomposition of titaniferous iron-ores in some of the earlier semi-metamorphosed sediments. The rutile of the Old Red Sandstone is certainly not authigenic, as it occurs in well-rolled and rounded forms; it may have been derived, as Rastall suggests, from titaniferous iron-ores, or some may have originated from sphene.

[1] 'Heavy Minerals in the Sandstones of the Scottish Carboniferous Rocks' Proc. Geol. Assoc. vol. xxiv (1913) p. 58.

[2] 'The Source of the Purple Zircons in the Sedimentary Rocks of Scotland' Trans. Edin. Geol. Soc. vol. xi (1923) p. 201.

[3] Geol. Mag. vol. lx (1923) p. 39.

V. The Unconformity between the Silurian and the Old Red Sandstone of the Cardiff Area.

In order to compare the Old Red Sandstone of the Cardiff area with the Silurian, typical specimens from the Silurian rocks of the Cardiff district have been examined. An exhaustive investigation of these sediments has not been completed, but sufficiently numerous specimens have been tested to establish the fact that the Silurian of the Cardiff area has a characteristic assemblage of minerals, which is entirely distinct from that of the Old Red Sandstone of the same area.

The most abundant heavy mineral residues occur in the Rumney Grit.[1] This has been selected as a typical coarse sediment of the Silurian of the Cardiff district. The heavy crop of minerals consists of a practically pure culture of zircons and irregular iron-ores.

The zircons, on the whole, are extraordinarily uniform in type and size, being generally colourless and more or less ovoid, although some few idiomorphic grains are present.

A few small well-rounded zircons occur, of a faint pinkish-brown colour (? purple types of Dr. Mackie); but the proportion of this type to the colourless grains is very small, when compared with that seen in the Old Red Sandstone. Brown tourmaline and rutile of a deep amber colour occur, although they are distributed but sparingly through the rock, one or two grains occurring in each separation. No garnets have been observed, and apatite has not been detected with certainty, although a few intensely-clouded well-rounded grains may possibly represent altered apatite.

The constituents of the lighter crops also present a characteristic and distinct assemblage.

The angular to subangular quartz-grains are much more uniform in size and shape than those of the Old Red Sandstone. No perfectly rounded grains have been observed. The quartz-grains exhibit practically no evidence of strain or regular inclusions. The muscovite of the Silurian, occurring in relatively small flakes generally free from inclusions, is also different from that of the Old Red Sandstone, where it is present in characteristically large cleavage-flakes, and generally contains regular and dust-inclusions, and sometimes sagenitic rutile. No plagioclases have been observed, although weathered aggregates occur. Cherts are present.

In short, the Silurian rocks of the Cardiff district are typically sediments which have been derived from pre-existing sediments; while the greater part of the Old Red Sandstone rocks, as will be shown later, were probably derived directly from metamorphic and igneous areas.

In view of this evidence and of the fact that distinct unconformities exist elsewhere, along the south of the Old Red Sandstone

[1] W. J. Sollas, Q. J. G. S. vol. xxxv (1879) p. 480.

of South Wales, as, for example, Gower,[1] Tortworth,[2] and the Mendips,[3] it is suggested that there is a distinct stratigraphical break between the Old Red Sandstone and the Silurian of the Cardiff district.

VI. The Probable Source of the Old Red Sandstone Sediments.

It is interesting to note the striking similarity which exists on the whole between the sediments of the Old Red Sandstone in the Cardiff area, those of the Torridonian, and also those of the Millstone Grit of Yorkshire as described by Prof. A. Gilligan. There are, of course, many differences, such as the shape of the grains and the grades of the sediments, due to different conditions of deposition.

Prof. Gilligan compares and contrasts the Millstone Grit of Yorkshire with the Torridonian Sandstone, in the following table.[4] For comparison, a brief summary of similar Old Red Sandstone types is inserted between the two:—

Torridonian.	*Old Red Sandstone of the Cardiff Area.*	*Millstone Grit of Yorkshire.*
(*a*) Presence of blue or opalescent quartz, with acicular, irregular, and regular inclusions.	(*a*) Similar pebbles abundant in Old Red Sandstone.	(*a*) Similar pebbles abundant in the Millstone Grit.
(*b*) Dominant felspars are microcline, microcline-perthite, oligoclase, and orthoclase. The characteristic felspars of the arkoses are microcline and microcline-perthite, quite fresh, unaltered.	(*b*) Microcline, oligoclase, and oligoclase-andesine are very abundant, and are characteristically very fresh; weathered orthoclase (?) abundant.	(*b*) Microcline and microcline-perthite are by far the most abundant and quite fresh.
(*c*) Cherts of various colours showing cryptocrystalline and microcrystalline structure. No definite organisms found.	(*c*) Cherts of various colours showing cryptocrystalline and microcrystalline structure. No trace of organisms found.	(*c*) Cherts of various colours showing similar structure, common in coarse beds. Some ghosts of organisms are found in a few of the chert-pebbles.
(*d*) Silicified oolites occur.	(*d*) None found.	(*d*) Exactly similar pebbles found.
(*e*) Quartzite-pebbles.	(*e*) Quartzite-pebbles.	(*e*) Quartzite-pebbles.
(*f*) Pebbles of vein-quartz which show evidence of shearing are the most abundant.	(*f*) Similar pebbles are the most abundant.	(*f*) This is also the case with the Millstone Grit.

[1] Sir Aubrey Strahan, 'The Geology of West Gower' Mem. Geol. Surv. 1907.

[2] F. R. C. Reed & S. H. Reynolds, 'On the Fossiliferous Silurian Rocks of the Southern Half of the Tortworth Inlier' Q. J. G. S. vol. lxiv (1908) p. 535.

[3] S. H. Reynolds, 'Further Work on the Silurian Rocks of the Eastern Mendips' Proc. Bristol Nat. Soc. ser. 4, vol. iii, 1912 (issued for 1911) p. 80.

[4] 'Petrology of the Millstone Grit of Yorkshire' Q. J. G. S. vol. lxxv (1919) pp. 284-86.

Torridonian.	*Old Red Sandstone of the Cardiff Area.*	*Millstone Grit of Yorkshire.*
(*g*) Felsites, gneisses, and mica-schists occur.	(*g*) Felsites (jasper), quartz-gneisses, and mica-schists occur.	(*g*) Pebbles of similar type occur.
(*h*) Clastic micas (both brown and white) are present in the finer-grained beds.	(*h*) White mica and chlorite (? after biotite) are very abundant, occurring in large flakes. Fresh brown mica has been observed in the cornstones and marls.	(*h*) Clastic micas (both brown and white) are present in the finer-grained beds.
(*i*) Heavy minerals include magnetite, ilmenite, sphene, garnet, tourmaline, zircon, and rutile. Dr. T. O. Bosworth (Rep. Brit. Assoc. Dundee, 1912, p. 474) points out the great abundance of garnet and zircon.	(*i*) Heavy minerals include ilmenite and leucoxene, pyrites, garnet, tourmaline, zircon, rutile, and apatite, with a very little magnetite.	(*i*) Heavy minerals include ilmenite, leucoxene, garnet, zircon, tourmaline, rutile, and magnetite. Of these by far the most important is garnet; while zircon is very common in all beds.
	(*j*) A large proportion of coloured to colourless zircons.	
	(*k*) Sandstone-pebbles of the Red Marl Group, not matched with older Palæozoic Rocks.	

The Torridon Sandstones are supposed to have been derived from a pre-Cambrian massif on the north-west, while Prof. Gilligan suggests a similar origin in the north-east for the Millstone Grits.[1] The above comparison, in our opinion, justifies the conclusion that the greater part of the Old Red Sandstone sediments of South Wales has been derived from a similar pre-Cambrian massif.

It will be noted that apatite is very abundant in the Old Red Sandstone of South Wales, while it is not recorded in any quantity from the Torridonian and the Millstone Grit. Prof. Gilligan comments on the absence of apatite[2] from the Millstone Grit. He records its presence, however, in granite-pebbles from the grit.

It is possible that the apatite of the Torridonian and the Millstone Grit has been removed by chemical agency, while that of the Old Red Sandstone has been preserved by different conditions of deposition and cementation. It is also possible, however, that areas of titaniferous magnetite, etc., similar to those of Norway (which contain large amounts of apatite), were undergoing denudation during Devonian times. This suggestion is borne out to some extent by the relatively considerable amount of titaniferous minerals in the Old Red Sandstone of South Wales.

The large proportion of faintly coloured and opaque zircons in comparison with those of the colourless type, in view of Dr. Mackie's recent work, suggests a first cycle of denudation from Lewisian or similar gneisses.

The sandstone-pebbles so abundant at several horizons in the Red Marl Group, which contained much fresh microcline and

[1] Q. J. G. S. vol. lxxv (1919) p. 286. [2] *Ibid.* p. 272.

oligoclase, have not been matched with any older Palæozoic sandstones, and may have been derived from an older source.

If a physico-chemical deposition be assumed for the cornstones, then areas of limestone must have been undergoing denudation.

Presumably then, most of the sediments under consideration have been derived from a pre-Cambrian land-mass, and represent the estuarine and deltaic (with lagoon) deposits, of a huge river which probably drained the pre-Cambrian massif on the north-west. This land-mass apparently consisted of a metamorphic and acid igneous complex, together with calcareous and arenaceous rocks, which had not been greatly deformed mechanically.

VII. The Base of the Devonian.

The intense earth-movements which marked the close of the Palæozoic Era, and added the mountains of Wales, the Lake District, Scotland, etc., to the great land-mass of pre-Cambrian rocks in the north-west, apparently resulted in the uplift of the greater part of South Wales. The unconformities between the Silurian and the Old Red Sandstone at Tortworth, the Mendips, in Gower, and (as this work has suggested) in the Cardiff area, clearly demonstrate the occurrence of this upheaval.

At first sight, these facts support the idea of the 'Welsh Lake' conditions of deposition.

Prof. L. D. Stamp [1] asserts that a ridge existed during Lower Old Red Sandstone times in the neighbourhood of the Bristol Channel; but Dr. J. W. Evans [2] doubts whether such a ridge ever existed in the Bristol Channel area.

However, in view of the discovery in the course of the work here described of a definite petrological break at the base of the Old Red Sandstone of the Cardiff area, there can be little doubt that there was an appreciable uplift in this area, towards the end of Silurian times. Yet, if this uplift resulted in the formation of a ridge of dry land, we are met with an apparent paradox; for not the slightest trace of Silurian sediments has been found in, or at the base of, the Old Red Sandstone. In fact, the lowest horizons contain pebbles which could only have originated from a metamorphic complex. It has already been noted that, petrologically, the Silurian sandstones and the Old Red Sandstone are absolutely distinct, and have been derived from entirely different sources. It is extraordinarily difficult to imagine that even a low-lying ridge would leave no traces in the immediately overlying sediments.

Thus, we are faced by two apparently conflicting facts:—(*a*) there was an uplift towards the end of the Silurian Period; (*b*) no detritus was contributed by the Silurian of South Wales to the Old Red Sandstone sediments in the Cardiff area.

In our opinion, these facts can only have one interpretation.

[1] Geol. Mag. vol. lx (1923) p. 394.
[2] *Ibid.* p. 479.

The uplift in pre-Devonian times did not result in much of the land emerging from the sea. The slowly rising sea-floor was subjected to contemporaneous submarine erosion, by currents flowing approximately southwards, and transporting the débris in that direction until subsidence began and permitted Old Red Sandstone sediments to accumulate.

In short, there is a marked non-sequence at the base of the Devonian in South Wales, but there was no, or little land-barrier formed, hence the hypothesis of the 'Welsh Lake' is untenable.

There was apparently little interruption in deposition in parts of Pembrokeshire[1] and the Shropshire area,[2] in earliest Devonian times. It is possible that normal sedimentation was taking place in a trough running approximately from the north of Shropshire to Pembrokeshire, although even parts of this area may have been undergoing contemporaneous erosion.

VIII. Conditions of Deposition.

The frequent and rapid alternation of impure limestones, generally conglomeratic, with gritty marls, sandstones, and pebble-beds, together with the nature of the sediments, ripple-marking and probably lenticular nature of most of the beds, suggest, on the whole, deltaic conditions for the deposition of the Old Red Sandstone of South Wales. During earlier Old Red Sandstone times, lagoons were probably prevalent, in which the impure cornstones were formed. The numerous pebble-beds, in which the constituents are well worn, with a large quantity of relatively coarse arenaceous transported material, suggest that the river which transported this detritus must have originated in a massive land-mass. Such a massif would presumably intercept moisture-bearing winds, and leave the leeward side comparatively dry, with conditions approaching those of a desert, where dreikanters would form, with well-rounded quartz-grains. Such an area, subjected to occasional or periodic floods, would give rise to the red deposit so characteristic of denudation under arid climatic conditions. The fresh felspars were probably derived from a fairly acid igneous rock by a process of disintegration by insolation, although the possibility of rock-disintegration under glacial conditions in the mountains must be taken into consideration.

IX. A Suggested Connexion with the Devonian of Devon.

If the Old Red Sandstone of South Wales represents a series of sediments deposited under deltaic and estuarine conditions, it may reasonably be suggested that the Devonian of North Devon is

[1] 'The Geology of the South Wales Coalfield: the Geology of the Country round Milford' Mem. Geol. Surv. 1916, p. 93.

[2] L. D. Stamp, 'On the Highest Silurian Rocks of the Clun Forest District' Q. J. G. S. vol. lxxiv (1918) p. 240.

merely an estuarine and marine phase of the South Wales Devonian, and has been at least partly derived from the same source. Detailed petrological investigation of the Devon facies will do much to establish or refute this suggestion, which is borne out to some extent by the occurrence of two fossiliferous marine beds at West Angle Bay, south of Milford Haven, in the Upper Old Red Sandstone; and by the presence of the undermentioned beds of Old Red Sandstone type in North Devon :—

(i) Foreland Beds with *Psilophyton*.
(ii) Lower and middle parts of the Hangman Grits.
(iii) Pickwell Down Sandstone.

Dr. J. W. Evans,[1] in criticizing adversely Dr. L. D. Stamp's recent assertion of the existence of the 'Welsh Lake', writes:

> 'Is there any reason to suppose that the south-eastern shoreline of the Silurian sea of the Welsh border was continued as an east-and-west ridge in the neighbourhood of the Bristol Channel? Even if it was, it could not have formed the boundary between the Old Red Sandstone and Devonian types of sedimentation, except for a comparatively short period.'

X. Summary and Conclusions.

The Coed-y-Coedcae Fish-Band, with *Pteraspis*, *Cephalaspis*, and *Pachytheca*, has been discovered, thus enabling a Dittonian age to be ascribed to that part of the Red Marl Group which overlies and includes the Fish-Band.

The cornstones have probably been formed mainly by physico-chemical processes; suggestions of the existence therein of foraminifera and algæ have, however, been observed.

The greater part of the sediments of the Old Red Sandstone of the Cardiff district has been derived from a metamorphic and acid igneous complex, together with some arenaceous and calcareous sediments, probably from a pre-Cambrian massif on the north-west (approximately).

There is a definite petrological, and hence presumably a stratigraphical, break at the base of the Old Red Sandstone of the Cardiff district.

There is no petrological evidence to support the suggestion of a 'Welsh Lake'.

It is probable that the Devonian of North Devon and the Old Red Sandstone of South Wales represent various facies of an originally continuous series of deposits.

In conclusion, we wish to acknowledge our great indebtedness to Prof. A. H. Cox for his invaluable advice and criticism; to Dr. J. F. North for his examination and criticism of many organic remains; to Dr. A. E. Trueman, and to the other investigators whose names have been mentioned in the text.

[1] Geol. Mag. vol. lx (1923) p. 479.

Discussion.

Mr. E. E. L. Dixon remarked that, as regarded the relations of the Old Red to the Silurian, the development in Southern Pembrokeshire marked an advance on the non-sequence suggested in the Cardiff district, and also supported the view, most recently expressed by Prof. L. D. Stamp, that, at various places in England and Wales, certain beds near the junction, though resembling the Silurian in some elements of their fauna, should be included in the Devonian. For, in the country around Pembroke and Tenby, the base of the Old Red contains frequent *Lingula*, a survivor of the Silurian fauna, but at the same time rests on the Ludlow unconformably. The junction is marked by a strong conglomerate of quartzites, quartzitic sandstones, and vein-quartzes, in which the felspathic material, abundant above, is rare.

On the other hand, the conclusions reached in Pembrokeshire as to the presence of land away to the south appeared to differ from those inferred from the Cardiff evidence. In this respect, the Lower Palæozoic and the Lower Old Red of Pembrokeshire differ from the Upper Old Red, which thickens greatly southwards, and, at several places in the southernmost outcrops, contains marine (Upper Devonian) intercalations; it has presumably formed part of a delta fringing the Devonian sea. The Lower Old Red and older rocks, on the contrary, yield evidence of the presence of land on the south. Thus, in Southern Pembrokeshire the Llanvirn Series is generally succeeded unconformably by the Ludlow, whereas on the north this hiatus is bridged, except for the break between the Lower and the Upper Llandovery. Again, north of Milford Haven, the Wenlock Series passes up into the Ludlow, and the latter, at most places, into the Old Red. On the south the Wenlock is separable from the Ludlow by a sharp line; the base of the Ludlow is conglomeratic and, in the southernmost outcrop, contains plant-beds without marine organisms. Moreover, the hiatus between the Ludlow and the Old Red increases on the whole southwards. The Ludlow is overstepped, and probably there is also overlap of the base of the Old Red.

The bulk of the material of the Lower Old Red may well have been derived, as stated by the Authors, from pre-Cambrian rocks, for strained quartz and fresh felspars are abundant, and Dr. Herbert H. Thomas has found some of the Cosheston Sandstones abnormally rich in garnet. The pebbles of sedimentary rocks can hardly, however, have come a great distance: they are abundant, and reach diameters of 18 inches in the basal conglomerate. In the Ridgeway Conglomerate, which appears to be represented in the Cardiff district by the Llanishen Conglomerate, their large size and their abundance, to the exclusion of any coarse felspar-bearing fragments, point to an origin that was close to Pembrokeshire, and can hardly have been far from Cardiff. A few have yielded horny brachiopods, and are possibly Cambrian; but nothing like these fossiliferous rocks is known in South Wales *in situ*. It is

difficult to avoid the conclusion that their source is now covered by the sea, and lies, partly at least, away to the south.

Mr. A. K. Wells regretted the unavoidable absence of the President, especially in view of the opinions expressed by the previous speaker. As a member of the Geologists' Association he had had the privilege of attending the excursion conducted by Dr. Evans in North Devon in 1922, and had been much impressed by the remarkable threefold alternation of marine with 'continental' deposits there developed. The succession is essentially intermediate in character between that of South Devon (marine) and that of South Wales (continental). The beds of continental facies in North Devon must increase in thickness northwards at the expense of the marine wedges, and merge into one thick continental series somewhere in the Bristol Channel. There thus appears to be neither room nor reason for the alleged ridge during the Devonian Period.

With regard to the pebbles and fragments in the Old Red Sandstone of the Cardiff district, he enquired whether it was not possible for some of these to have been derived second-hand from the Cambrian beds of the Harlech Dome, say, from the Rhinog and Barmouth Grits. Some of the rock-types could be matched in the Basement Series of the Ordovician of Merioneth, which the speaker believes to be, in part at least, redistributed Harlech material.

Dr. A. Morley Davies pointed out that the evidence for what the Authors termed a 'petrological non-sequence' was not quite analogous with the palæontological evidence of a non-sequence. If the change in the mineral contents of sediments were due to the gradual removal of overlying rocks and the increased exposure of a deeper series, abruptness in the change would certainly seem to indicate a time-interval unrepresented by sediments. But, if the change were due to an alteration in the direction of transport of minerals, abruptness was not necessarily inconsistent with continuous deposition.

Prof. A. Hubert Cox remarked that the paper afforded one more instance that a petrological examination might shed new light on the origin of a sedimentary formation. To himself the present results were rather unexpected, but the evidence was so conclusive as to leave no room for doubt that pre-Cambrian rocks had contributed very largely to the Old Red deposits, and that Palæozoic formations had not contributed so largely as might have been expected. He was much interested in Mr. Dixon's remarks, because he had recently examined new exposures of what he believed to be the Llanishen Conglomerate, in excavations for the Wenallt Reservoir near Cardiff. The pebble-beds do not compare in thickness with the 1000 feet of the Ridgeway Conglomerate; but the pebbles themselves answer closely to the description just given by Mr. Dixon. They are mostly coloured quartzites, which he had failed to match with any Lower Palæozoic rocks, but occasional pebbles of coarser grain resembled some of the Lower Cambrian grits of North Wales, such as the Bronllwyd Grit. He

had not obtained any derived fossils; but the suggestion of a Lower Cambrian derivation received additional support from Mr. Dixon's record of forms like *Kutorgina* from the Ridgeway Conglomerate.

The SECRETARY read the following contribution to the Discussion sent by Prof. P. G. H. Boswell:—

'I very much regret my inability to be present at the reading of the paper. Having some slight knowledge of the petrographical characters of the Devonian deposits north and south of the area considered by the Authors, I am interested to see that they find themselves compelled to turn to the north-west for the source of the material, and to exclude the older Palæozoic sediments. Speaking generally, in this conclusion I think that they are correct. Both the coarser and the finer constituents which they describe suggest a source in pre-Cambrian (probably Archæan) rocks. The assemblage of strained quartz, chlorite, tourmaline, garnet, and microcline is characteristic; it would be interesting to know whether large rose-purple ovoid zircons find a place in it. The pre-Cambrian types exposed in the Malverns, Shropshire, and Pembrokeshire are not competent to yield such an association; but it should be remembered that the petrological investigation of those rocks has not yet been intensively carried out. One feels a great temptation to turn to the Carnarvonshire area, where the Archæan of Anglesey would satisfy the demands. It is, however, important to remember that ancient massifs exposed in Devonian times may now be covered by later deposits.

'That the Authors are correct in stating that older Palæozoic rocks would not yield the assemblage, I do not doubt. The influence of the Archæan rocks on the petrology of the Algonkian sediments is well known. Thereafter, throughout the Cambrian, Ordovician, and Silurian Periods, the abundance and variety of the detrital minerals in the corresponding British sediments steadily decreases, until, when the basin of deposition was almost filled in later Ludlow times, the assemblage was dull in the extreme. Subsequent earth-movements resulted in an area of ancient and crystalline rocks being once again drawn upon to provide the early Devonian sediments. As was the case repeatedly in the geological history of these islands, the "Old Boy," to use Lapworth's homely, illuminating and, in this connexion, peculiarly appropriate term, was time after time the father of British sediments.'

Prof. W. J. SOLLAS recognized the importance of the results which the Authors had brought before the Society. He desired, however, additional information on the mode of occurrence of the dodecahedral cleavage in garnets. He had never observed cleavage in thin slices of garnets, and thought that its presence under other conditions, though frequently asserted, might be open to other interpretations.

A petrographical break scarcely implied a stratigraphical unconformity, although it might well mark a change in physical conditions. In the neighbourhood of Cardiff there was, to all appearance, a gradual passage from the Silurian to the Old Red Sandstone, and this was true also of the succession so finely displayed on the northern side of the area in the Sawdde section.

Mr. W. CAMPBELL SMITH and the CHAIRMAN also spoke.

Dr. HEARD, replying on behalf of the Authors, was glad to know that Prof. Boswell had arrived at similar conclusions, with regard to the Old Red Sandstone of certain other areas.

Prof. COX had already referred to the Llanishen Conglomerate

mentioned by Mr. Dixon, and a detailed account of this conglomerate is contained in the paper.

The views as to the relation of the Old Red Sandstone of South Wales and the Devonian of Somerset, which Mr. Wells had put forward, were essentially those held by the Authors. The paper attempted to show the important part played by pre-Cambrian rocks, in furnishing directly sediments to the Old Red deposits. The Authors do not deny the possibility of some of the material having been derived from other rocks.

In reply to Dr. Morley Davies, Dr. Heard said that the term non-sequence was so well-known as implying the absence of certain strata, due to penecontemporaneous erosion, that the Authors felt justified in using it, even in a case where the non-sequence has not been proved by palæontological evidence. Conglomerates are not confined to one or even two horizons. Besides the main conglomerate-bands, fine quartz-conglomerates also occur at the base of the Old Red Sandstone, as well as in the Coed-y-Coedcae Fish-Band.

He thanked Prof. Sollas for his kindly criticism, and was interested in the occurrence of garnets with a well-marked parting in certain schists.

He felt that the hypothesis of a 'Welsh Lake' had filled a useful purpose; but the evidence in the Cardiff district was, that there was no ridge which could have separated such a lake from the marine area of Somerset.

21. *The* VOLCANIC SERIES *of* TREFGARN, ROCH, *and* AMBLESTON (PEMBROKESHIRE).

By HERBERT HENRY THOMAS, M.A., Sc.D., F.G.S., and Prof. ARTHUR HUBERT COX, D.Sc., Ph.D., F.G.S. (Read April 9th, 1924.)

[PLATE XL—GEOLOGICAL MAP.]

CONTENTS.

I. INTRODUCTION.

THE area dealt with in this communication and represented by the appended map (Pl. XL) is situated some 5 miles north of Haverfordwest, 7 miles south of Fishguard, and from 8 to 14 miles east of St. David's. About 25 square miles in extent, it lies immediately north of a district recently resurveyed by the officers of H.M. Geological Survey,[1] and south and east of a tract of country surveyed by one of us (in collaboration with Prof. O. T. Jones)[2] in 1912. It is occupied mainly by Arenig and associated Upper Cambrian rocks, of which the Arenig Series is of especial interest, since it contains two distinct sets of volcanic rocks—one of which immediately underlies the lowest visible Arenig sediments. In addition, an important series of rhyolitic lavas and ashes of uncertain age traverses the greater part of the district from Roch to Trefgarn.

As is usual in Pembrokeshire, the general strike is in an east-north-easterly to west-south-westerly direction; but strike-faulting on an intensive scale has greatly disturbed the geological succession,

[1] 'The Country around Haverfordwest' Mem. Geol. Surv. Explan. Sheet 228, 1914; and 'The Country around Milford' *ibid.* Explan. Sheet 227, 1916.

[2] H. H. Thomas & O. T. Jones, 'The Pre-Cambrian & Cambrian Rocks of Brawdy, Hayscastle, & Brimaston' Q. J. G. S. vol. lxviii (1912) p. 374.

and complicated the structure of the district. On the south, this area of Arenig and Upper Cambrian rocks is followed by extensive outcrops of the higher Ordovician beds of the Haverfordwest district, while its northern boundary is constituted, in large measure, by the pre-Cambrian massif of Hayscastle.

(*a*) Physical Features.

Topographically, the district is rather more varied than is usually the case in Western Pembrokeshire. Considerable portions of the area are occupied by the 400-foot plain; but out of this rises a ridge of rhyolitic volcanic rocks which attains an altitude of nearly 600 feet above O.D. on Plumstone and Great Trefgarn mountains. Along this ridge the rhyolites crop out at intervals as craggy tor-like masses, as at Roch Castle, Cuffern, Poll Carn, and Trefgarn Rocks, otherwise the outlines are smooth. This ridge, contrary to expectation, does not constitute the main water-parting of the district, for the area is traversed by the River Cleddau, which has carved a deep gorge-like valley that runs approximately north and south, and traverses all the solid formations inconsequentially. Various tributary streams, notably the Sealy River and the Spittal Brook, have likewise incised deep valleys that bear little or no direct relation to the solid geology. These steep-sided valleys furnish numerous exposures that are augmented by a fair number of quarries. In the case of the Cleddau Valley the natural exposures are amplified by cuttings along the Great Western Railway line to Fishguard, on one side of the valley; and by the cuttings along Brunel's projected railway on the other. On the high-level plain, exposures are usually poor and scanty, and topographical features connected with the solid geology are either small and obscure, or altogether wanting. Considerable areas, and especially shallow depressions, are covered with thin drift that renders much of the solid geology obscure: as, for example, between Rinaston and Ambleston, and around Dudwell.

Along the outcrops of some of the harder rock-bands, such as the Sealyham keratophyres, and the Arenig and Roch rhyolites, occasional masses rise out of the high-level plain in a seemingly capricious manner, reminiscent of sea-stacks, and in the distance looking like ruined castles. Some of these have been in part destroyed by glaciation, and the resulting débris carried southwards and south-eastwards. These glacially-distributed boulders occasionally occur in such numbers and are so prominent a feature, that they may easily be mistaken for a weathered outcrop. Examples of such a distribution of boulders, hiding the true solid geology, may be seen south of Garn Turne Rocks, in the neighbourhood of Little Trefgarn, and south of the igneous rocks of Ambleston. In the distribution of drift, erratics, and crag-and-tail the district shows evident signs of extensive glaciation, but actual roches moutonnées are not often to be seen; the best occur on the crags of rhyolite which flank the Cleddau Valley at Trefgarn Rocks.

(*b*) Previous Literature.

On account of the craggy and picturesque outcrops of several of the rock-masses, such as those of Roch, Trefgarn, and Ambleston, the district early attracted the attention of geologists, and we find references in the writings of Murchison, Aveline, H. T. de la Beche, and Ramsay.[1] The state of our knowledge of the rocks of this area was summarized in 1857 by the publication by the Geological Survey of Sheet 40 of the Map, and Sheet No. 1 of Horizontal Sections. In these publications the main outcrops of the igneous rocks, designated felspathic trap, were indicated; and the associated sedimentary rocks were designated either Cambrian, altered Cambrian, or Llandeilo.

From the writings of the early geological surveyors, and from the maps and sections of the Geological Survey, it is far from clear whether the igneous rocks of Roch and Trefgarn were regarded as of intrusive or as of extrusive character; but that the former view had supporters is evident from the manner in which Dr. Hicks in his later papers emphasized the proofs of their volcanic nature. Some twenty years after the Survey published their map, Hicks,[2] extending his researches on the pre-Cambrian rocks of Pembrokeshire, made his first reference to the igneous rocks of Roch and Trefgarn, and claimed them as pre-Cambrian. He gave a good description of the Roch Series, and in this he was assisted by T. Davies. In that paper he published a north-and-south section along the line of the Cleddau Valley, from Trefgarn Bridge to Ford. In its main points this section resembled that of the Survey (1857), but Hicks grouped together the Trefgarn and Roch igneous rocks; and, ignoring the Arenig sediments that are exposed between them, he erroneously regarded the Trefgarn andesites as belonging to his newly-formed 'Arvonian Group' of the pre-Cambrian. In 1881 the error in his original section was perpetuated and intensified in another section illustrating an important paper on Classification which was published in the 'Popular Science Review' of that date.[3]

In 1885 Dr. J. E. Marr & Mr. T. Roberts[4] made a notable advance in our knowledge of the sedimentary rocks bordering the south of the district dealt with in this paper. They described, also, in detail the rocks of a quarry near Trefgarn Bridge, where they collected the first trilobites obtained from the *Lingula* Flags of this district. Through obscurity of the section, however, they

[1] See the bibliography given in the paper by H. H. Thomas & O. T. Jones on the Pre-Cambrian & Cambrian Rocks of Brawdy, &c., Q. J. G. S. vol. lxviii (1912) p. 377.

[2] 'A New Group of Pre-Cambrian Rocks (Arvonian) in Pembrokeshire' Q. J. G. S. vol. xxxv (1879) p. 285.

[3] 'The Classification of the Eozoic & Lower Palæozoic Rocks of the British Isles' Pop. Sci. Rev. n. s. vol. v (1881) p. 295.

[4] 'The Lower Palæozoic Rocks of the Neighbourhood of Haverfordwest' Q. J. G. S. vol. xli (1885) p. 476.

somewhat dubiously regarded the *Lingula* Flags as lying unconformably on the igneous rocks (Trefgarn Series). Later (1886) Hicks[1] revisited this quarry; he also regarded the junction as unconformable, and thus reiterated his belief that the igneous rocks there exposed were of pre-Cambrian age. Before the opening-up of the good sections of the Spittal Tunnel, just above the quarry in question, one of us[2] held the same opinion; but now, from the more complete exposures, we know that the junction is a thrust, and that the igneous rocks are of Arenig age (p. 530).

Since that date little has been published that is directly connected with the district, except passing references in those memoirs of the Geological Survey which deal with the area on the south, and have already been cited (p. 520).

II. The Stratigraphical Succession.

In the southern portion of the area represented by the map (Pl. XL) various divisions of the Ordovician occur, and their outcrops are delineated. These include the Ashgillian (Redhill and Slade Beds), the Caradocian (*Dicranograptus* Shales), Llandeilo Flags and limestone, *Didymograptus-murchisoni* Beds, and the Lower Llanvirn (*D.-bifidus* Beds). The sequence, lithology, and faunal characters of these divisions in Pembrokeshire are well known, and they have been sufficiently described in the Survey Memoirs on the geology of the country around Haverfordwest and Milford. It will, therefore, only be necessary to deal with that portion of the succession which directly concerns the age of the Roch, Trefgarn, and Sealyham volcanic series, and the structure of that region in which the igneous rocks occur—that is to say, from the Lower Llanvirn downwards.

The probable descending stratigraphical succession is indicated below, in tabular form:—

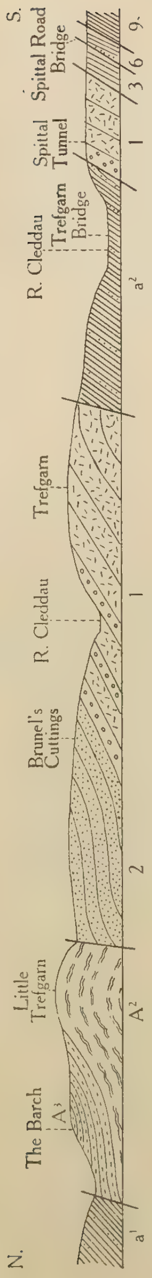
Arenig–Llanvirn...	Sealyham Group	Sealyham keratophyres. Sealyham shales.
Arenig	*Tetragraptus* Beds	*Tetragraptus* Shales. Brunel Beds.
	Trefgarn Andesitic Series.	
Upper Cambrian ...	*Lingula* Flags.	
Uncertain age .... ? Pre-Cambrian	Roch Rhyolitic Series	Nant-y-Coy Beds. Roch Rhyolites.

As will be seen from the map, these divisions are frequently in faulted relation to each other. As a whole, the sedimentary rocks are poorly fossiliferous, and frequently much affected by cleavage. Further, although they are of different ages, lithological differences are often slight, the whole combining to make the task of

[1] H. Hicks, 'The Pre-Cambrian Age of certain Granitoid, Felsitic, & other Rocks in North-West Pembrokeshire' Q. J. G. S. vol. xlii (1886) p. 351.

[2] H. H. Thomas, 'Notes on the Railway-Cuttings between Clarbeston Road & Letterston in Pembrokeshire' Summary of Progress for 1904, App. iv, Mem. Geol. Surv. 1905, p. 170.

Generalized section along the Cleddau Valley, from Ford to Spittal Tunnel.



9 = *Dicranograptus* Shales. 2 = Brunel Beds. a^1 = Ford Beds (? Solva).
6 = *Didymograptus-bifidus* Beds (shales and ash). 1 = Trefgarn Andesites. A^3 = Nant-y-Coy Beds.
3 = *Tetragraptus* Shales. a^2 = *Lingula* Flags. A^2 = Roch Rhyolites.

[Horizontal scale: 3 inches = 1 mile, or 1 : 21,120. Vertical scale exaggerated.]

unravelling the structure of the sedimentary deposits and the precise dating of the associated igneous rocks one of extreme difficulty.

In view of the complexity of the district and the uncertainty as to the exact stratigraphical position of several of the rock-groups, it will be convenient to give first the apparent succession as observed in the Cleddau Valley.

III. The Cleddau-Valley Section.

The Cleddau traverses the district from north to south, and is thus generally transverse to the strike of the rocks. The steep sides of its valley, aided by quarries and various railway-cuttings, furnish an almost continuous section. What is missing on one side of the valley may be filled in from exposures on the other. The main section commences near about where the Spittal Brook enters the Cleddau Valley, and it continues northwards in a seemingly ascending sequence to Ford.

Another important section, also in the Cleddau Valley, is on the eastern side, and ranges southwards from the Spittal Brook. It includes the quarry-section described by Marr & Roberts, and also the new and important exposures laid open at the mouth of the Spittal Tunnel.

(*a*) From the Spittal Brook to Ford.

(1) *Lingula* Flags.—The section commences with *Lingula* Flags, which are the oldest fossiliferous rocks of the neighbourhood. They are dark olive-grey flags and bluish shales, and show that rapid alternation of coarse and fine sediment so characteristic of beds of this formation. They are exposed on both sides of the Spittal Brook, and dip

northwards towards the Trefgarn andesites at an inclination of about 40°. As the andesites are approached, the valley narrows, and, although the actual junction with the *Lingula* Flags is not clearly visible, it can be located with sufficient accuracy to show that it must be a fault. The junction appears to cross the valley as an almost straight line, suggesting that this fault is one of high inclination.

(2) The Trefgarn Andesites.—This igneous series now occupies both sides of the valley for a distance of about half a mile. Its southernmost representatives, as exposed along the railway-line in the first cutting north of Spittal Brook, have a southward and eastward dip, and thus strike discordantly towards the *Lingula* Flags. An eastward dip is also to be observed in the new quarry (Council Quarry) on the eastern side of the valley. In this southern portion of the andesitic series we are evidently dealing with the central part of an eastward-pitching anticline, of which the southern limb has been cut out by the fault that separates the andesites from the *Lingula* Flags. The lowest rocks consist of moderately compact, bluish-green, keratophyric or andesitic lavas, followed by purple, red, and green tuffs and lavas of andesitic composition. Higher up the valley the dip gradually swings round to the north, and the rocks, with minor folding and some faulting, continue with a fairly steady northward inclination of about 20° to their northern boundary. As far as the large quarry on the Fishguard Road, immediately south of a sharp bend in the river, the series consists of alternating lavas and tuffs of the prevalent purple and green tints. It would appear, however, that tuffs preponderate in the higher portion of the series, and a thickness of about 40 feet of these is exposed in the quarry.

These tuffs are succeeded immediately by a massive volcanic conglomerate some 30 to 50 feet thick, which consists of large rounded blocks of andesite, ranging from a few inches to a foot in diameter, set in a pyroclastic matrix. This is followed by more tuffs and lavas, of the same type as those previously encountered; but exposures are not continuous, and the relative proportion of lava and tuff is difficult to ascertain. The uppermost member of the series appears to be another volcanic conglomerate that is well exposed between the main road and the river. It has a thickness comparable with that of the conglomerate already mentioned, and like it rests upon purple and green tuffs.

Occupying a position midway between these two conglomerates, which are both exposed on the western side of the valley, there is yet another conglomerate that forms a bluff on the eastern side. Whether there are three separate horizons on which these conglomerates occur, or whether there is some repetition by strike-faulting, is uncertain.

The maximum exposed thickness of this volcanic series is certainly to be encountered in the Cleddau Valley. It cannot be less than 500 feet, and is probably in the neighbourhood of

750 feet. The petrography of these rocks is of a simple and straightforward character, and need not be elaborated here. The lavas are mainly albitic pyroxene-andesites and keratophyres, and their essential characters have been described and figured in the Geological Survey Memoir on the Haverfordwest district.[1]

(3) The Brunel Beds.—The Trefgarn andesitic series is succeeded conformably by a thick group of sandy strata of proved Arenig age. These beds are best exposed in the cuttings made along the eastern side of the valley by Brunel[2] in 1845, when a line of railway from London to Fishguard was planned, but not completed. They may also be seen to advantage on the western side of the valley between the Fishguard road and the river, as also in a cut made to divert the river when the present railway was constructed.

The lowest beds of the group are not exposed in the Cleddau Valley, but are visible at numerous localities farther east, where they show an almost complete transition into the andesitic rocks below (p. 532). The southernmost of Brunel's cuttings shows about 60 feet of well-bedded, blue, ashy sandstones, current-bedded, with laminæ of dark micaceous shale. These are underlain by dark-grey shales and tuffs, and pass upwards into grey, striped, sandy shales and ashy sandstones. From the intercalated beds of shale in Brunel's cutting Mr. John Pringle obtained specimens[3] of *Callograptus salteri* Hall, *Dendrograptus flexuosus* Hall, *Dictyograptus irregularis* Hall, *Didymograptus extensus* Hall. and *Phyllograptus* cf. *typus* Hall. This assemblage of forms proves at once the Lower Arenig age of the Brunel Beds, placing them low down in the *Extensus* Zone.

The dip of the beds is east of north, at an average inclination of 20°, and this continues for the greater part of the outcrop in the valley. As, however, the rhyolites are approached there is some

[1] H. H. Thomas, in 'The Geology of the Country around Haverfordwest' Mem. Geol. Surv. 1914, pp. 21–23.

[2] We are indebted to Mr. A. C. Cookson, Engineer to the Great Western Railway, for the information contained in the following note:—The cuttings on the eastern side of the Cleddau Valley between Trefgarn Rocks and Trefgarn Bridge were made by the great engineer, I. K. Brunel, about the year 1845, when he was building the South Wales Railway, and it was then intended that the terminus should be at Fishguard. In 1851, however, the project of carrying the line from Clarbeston Road to the northern coast of Pembrokeshire was abandoned, and, the line being deflected southwards, the terminus was made at New Milford, now called Neyland, on Milford Haven. The point of departure of Brunel's projected line from the Neyland Branch was that adopted by the Great Western Railway Company when they made their line to Fishguard in 1904. It is interesting to note that Brunel's original scheme was ultimately put into operation, even to the extent of a practically identical route and the utilization of some of the cuttings made by him more than sixty years before.

The cuttings to which reference has been made in the text have not been utilized by the new line, as they were found to be at too high a level, and lay east of the course finally adopted.

[3] Preserved in the collections of the Geological Survey.

evidence of rolling, for the exposures in the new river-cut and on the western side of the valley near by, show variable dips, occasionally with a southward or eastward inclination. Allowing for the probable slight folding of these beds, their thickness, as exposed in the Cleddau Valley, must exceed 500 feet.

For a distance of about 150 yards before the rhyolites, next to be described, are reached, all exposures fail. The valley sides have a more gentle angle, the ground is wet and marshy, and the way in which the rhyolites on the north rise like a wall across the valley leaves no doubt, even if proof were lacking elsewhere, that the line of demarcation between these two formations is a fault or thrust of high inclination.

(4) The Roch Rhyolitic Series.—This series, as exposed in the Cleddau section, consists of two conformable units: a lower mass of flinty rhyolites and rhyolitic ashes, and a higher group of ashy flags and shales to which the name Nant-y-Coy Beds has been assigned.

(*a*) The flinty rhyolites and ashes.—The rhyolites are well exposed in the fine crags of Trefgarn Rocks and in the corresponding crags of Little Trefgarn on the other side of the valley. The presence of this barrier of resistant rock causes a marked constriction of the valley, and gives rise to some of the most picturesque scenery in Pembrokeshire.

The rhyolites are typically fine-grained, highly silicified, pale greenish-blue rocks that weather white. Originally, in all probability, they were vitreous, but are now microcrystalline. They are uniform in character, and rather featureless; for they are non-porphyritic, and exhibit no special structures beyond occasional slight indications of flow. Associated with them are equally flinty but beautifully banded silicified tuffs of blue-green and pale mauve tints, spoken of by Murchison as the 'ribbon-jaspers' of Macculloch. These flinty ashes are best seen where the main road has been cut through the base of the crags.

Where first encountered the rhyolites have a south-south-eastward dip of about 15°; but they soon become horizontal, and turn over towards the north. The general disposition of the rocks suggests an eastward-pitching anticline, of which the southern limb has been cut out by the fault or thrust that separates the rhyolites from the Brunel Beds.

(*b*) The Nant-y-Coy Beds, so called from their excellent exposures along the course of the Nant-y-Coy—a small stream draining eastwards into the Cleddau at Nant-y-Coy Mill—are of pyroclastic nature, and succeed the rhyolites conformably. They are of considerable thickness, and consist of flaggy silicified pyritous ashes that bleach white, but, on account of their pyritic character, give rise to a characteristically yellow soil. Their unbroken junction with the underlying rhyolites is best seen in the railway-cutting and in the crags above. The lowest beds are rather more massive and more pyritous than those which succeed

them, and when partly weathered show a pronounced red staining. In the pyritic nature of these deposits is probably to be found the reason for the name 'gold rocks' applied locally to the crags through which the railway-cutting has been made. They also contain traces of copper. On the western side of the valley the lower beds are well exposed behind Nant-y-Coy Mill, and on the footpath leading to Trefgarn Rocks. The succeeding more typical deposits are rather more thinly bedded, flaggy, and often striped. Some of them are so thinly bedded as to be almost papery; others are more massive, and have the splintery jointing characteristic of a chinastone-ash or hälleflinta. They are best seen in the precipitous northern bank of Nant-y-Coy, where the rocks can be examined in an unweathered condition. East of the river they occupy several hummocks on the low ground, and then form the striking steep-faced hill of the Barch.

The width of outcrop clearly indicates that the group, as a whole, is of considerable thickness; but, towards their northern limit, the beds assume a southward dip, and give other signs of minor folding. This, taken in conjunction with the fact that their northern boundary is always a fault, precludes the possibility of ascertaining the actual thickness; it cannot be much less, however, than 600 feet, as exposed on the valley sides.

(5) The Ford Beds.—The fault that marks the northern boundary of the Nant-y-Coy Beds throws them in turn against the pre-Cambrian and Cambrian rocks of the Hayscastle mass that lies west of the Cleddau Valley, against Ford Beds in the Cleddau Valley itself, and, on the east, against the Sealyham Shales (Arenig or Llanvirn).

The Ford Beds have already been described by one of us and Prof. O. T. Jones.[1] They consist of a thick series of blue-grey rusty-weathering shales. Sometimes they are rather flaggy, and contain thin bands, an inch or so thick, of banded quartzite similar to the siliceous courses met with in the *Lingula* Flags. The beds are but little affected by cleavage, and are well exposed in the railway-cuttings at Wolf's Castle Station, Chapel Farm, and towards Musland. Nevertheless, after prolonged and careful search, they have failed to yield a single fossil. They appear to pass downwards into a sandstone—the Musland Grit; but their exact age remains an unsolved problem.

These beds are much affected by minor folding, but they have a general north-eastward dip away from the Lower Cambrian and pre-Cambrian of Hayscastle, and towards the Ordovician rocks of the Sealyham district; from these, however, they are separated by the Pwll-Strodyr Fault.

Their lithology recalls in some respects that of the *Tetragraptus* Shales and in some measure that of the *Lingula* Flags. It is

[1] H. H. Thomas & O. T. Jones, 'The Pre-Cambrian & Cambrian Rocks of Brawdy, Hayscastle, & Brimaston' Q. J. G. S. vol. lxviii (1912) p. 393.

difficult to see, however, how they could belong to either of these formations, and they were provisionally assigned to the Upper Solva division of the Cambrian. We have no further evidence to offer on this point, but it is possible that more detailed work in the Cambrian succession of the Solva district may assist in forming a final conclusion.

(6) The Sealyham Group.—The Ford Beds are thrown by the Pwll-Strodyr Fault against various members of the Sealyham Group. This group consists of a thick series of blue-black shales and thinly-bedded mudstones of *Didymograptus-bifidus* or *D.-extensus* age, with which are intercalated flows and ashes of keratophyric character. These igneous rocks are quite distinct, both lithologically and stratigraphically, from the Trefgarn Andesites already described. The rocks of the Sealyham Group will be discussed more fully in a later portion of this paper (p. 535).

(*b*) Trefgarn Bridge and Spittal Tunnel.

The Spittal-Tunnel section, which has a total length of about 900 yards, is one of the most important sections in the district: for it cuts across the strike of a diversity of rocks, and exhibits well their mutual relations. The cutting leading to the tunnel at its southern end is extremely interesting, and has already been described by one of us.[1] It is sufficient here to state that at the southern end it commences in *Dicranograptus* Shales, and between this point and the Spittal-Road bridge shows a northward-dipping ascending sequence of those beds which represents almost the complete succession as developed in South Wales. The horizons range from the zone of *Nemagraptus gracilis* to that of *Dicranograptus clingani* or *Pleurograptus linearis*. Immediately north of the road-bridge a thrust of high northward inclination brings in a small thickness (some 150 to 200 feet) of *Didymograptus-bifidus* Shales with overlying thickly-bedded ashes. Another thrust of similar character then introduces *Tetragraptus* Shales, which occupy the cutting to the tunnel's mouth and continue inside for a distance of some 90 yards: at that point, with marked disturbance, they are succeeded by igneous rocks of the Trefgarn Series. The *Tetragraptus* Shales here exposed have a thickness of about 250 to 300 feet. Keratophyric and andesitic rocks occupy the remaining portion of the tunnel, and are exposed in the cutting at the northern entrance. One of the chief matters of interest brought out by the cutting up to this point is the nature of the faulting or thrusting whereby an apparently inverted succession is produced. Each formation dips towards the north, and is succeeded in that direction by another older than itself. It can be shown that there is no inversion within any unit, and thus the

[1] H. H. Thomas, in 'The Geology of the Country around Haverfordwest' Mem. Geol. Surv. 1914, pp. 49–51; see also pp. 20, 30.

explanation of the sequence is that continuously older beds have been thrust over successively from the north (fig. on p. 524).

It is the northern portion of the cutting that, in the present connexion, holds for us the greatest importance, for here is obtainable undoubted proof of the overthrust nature of the junction between the igneous series and the apparently succeeding *Lingula* Flags. The igneous rocks are steeply inclined, and are largely volcanic conglomerates that are formed of rounded masses of andesitic igneous rocks (measuring up to many inches in diameter) set in a matrix of identical but comminuted material. This similarity between pebbles and matrix in some instances effectively masks the conglomeratic nature of the rocks in question, and this does not become evident until weathering has proceeded to a considerable extent.

The igneous rocks are succeeded on the north by *Lingula* Flags that are thrust over them, lie discordantly across their edges, and continue to the northern end of the cutting. The weathering of the volcanic conglomerates beneath the thrust-junction with the *Lingula* Flags has brought strongly into evidence, for a short vertical distance, their conglomeratic nature; and this, at first sight, since it follows the *Lingula*-Flag boundary, might be taken for a conglomeratic base of the overlying formation. It was this deceptive appearance, coupled with the fact that a plane of movement in the igneous rocks was more or less parallel, and close, to the thrust on which the *Lingula* Flags rested, that led Marr & Roberts to suggest a pre-*Lingula*-Flag age for the igneous rocks, and a conglomeratic base for the *Lingula* Flags as exposed in the roadside quarry. It will be seen, from what has been said regarding the nature of the faulting and succession as shown by the tunnel-section, that successively older rocks succeed each other towards the north. Therefore, we should expect, even without additional evidence, the *Lingula* Flags to be older than the igneous rocks that they apparently overlie.

The olive-green flags, overlain by glacial gravel, at the entrance to the cutting, yield abundant *Lingulella davisi* (M'Coy); while from the quarry below, on the Fishguard road, the following forms have been obtained:—*Agnostus pisiformis* (Linné), var. *obesus* Belt, *Olenus cataractes* Salter, and *O. mundus* Lake—a fauna that suggests the Lower *Lingula* Flag (Maentwrog) Stage.[1]

Northwards to the Spittal Brook the ground is occupied by these beds, with a general northward dip, and the section here joins that of the Cleddau Valley already described (p. 524).

[1] See 'The Geology of the Country around Haverfordwest' Mem. Geol. Surv. 1914, p. 12.

IV. Distribution of the Rocks, and Confirmatory Sections.

(*a*) The *Lingula* Flags.

East of the Cleddau Valley the outcrop rapidly narrows towards Spittal, near which locality the *Lingula* Flags are cut out entirely by the confluence of the two faults or thrusts that form respectively their northern and southern boundaries. Over this tract of country they are fairly well exposed along the Spittal Brook towards the Woollen Mill, and in most of the lanes and roads, while their characteristic yellow-weathering débris is abundant. Most localities will yield *Lingulella davisi* on diligent search. West of the Cleddau the area occupied by these rocks is of much greater extent. The outcrop widens rapidly from the Cleddau by reason of the northward trend of its boundary against the andesites through Trefgarn Village towards the rhyolites of Poll Carn. The *Lingula* Flags are here brought into contact with the Roch Rhyolitic Series, and so continue along the southern flanks of Great Trefgarn, Plumstone, and Dudwell Mountains. Old quarries on Great Trefgarn Mountain have yielded abundant *Lingulæ*. On the south, as in the Spittal-Tunnel section, their outcrop is bounded more or less consistently by members of the Trefgarn Volcanic Series, and possibly some Brunel Beds, to the neighbourhood of Cuffern, where they are completely cut out, the Roch and Trefgarn Series being brought together. Within this tract they are well exposed around Leweston and Wolfsdale Hill. At the former locality they yielded several fossils to Marr & Roberts, and from Leweston Farm we have obtained *Agnostus pisiformis* var. *obesus*. They are seen with their characteristic lithology and abundant *Lingulæ* in an old quarry at Lady's Cross; but on the west their outcrop is largely drift-covered. What are presumably Lower *Lingula* Flags with some Menevian deposits appear on the north side of the Roch Rhyolites, on the western slopes of Cuffern Mountain, and continue westwards to Roch Bridge by way of Ferny Glen. They evidently belong, structurally, to the southern limb of the Hayscastle Anticline: for, with a southward dip, they are followed northwards by still lower members of the Cambrian System.[1]

They are fairly fossiliferous, and yield *Agnostus pisiformis* (Linné), *A. pisiformis* (Linné), var. *obesus* Belt, *Lingulella ferruginea* Salter, etc.

(*b*) The Trefgarn Andesites.

Apart from the main section of the Cleddau Valley there are no very good exposures of the northern mass, except in the Spittal Brook, where a good section is to be seen behind the buildings of the Spittal Woollen Mill. East of this locality they more or less

[1] H. H. Thomas, in 'The Geology of the Country around Milford' Mem. Geol. Surv. 1916, p. 17.

rapidly turn into the fault that forms their southern boundary, and are soon cut out. Their passage into the higher beds (Brunel Beds) will be discussed later (p. 544).

The mapping reveals the fact that the southern mass, as exposed at Trefgarn Bridge and the Spittal Tunnel, is of quite small extent, but that it appears again on the western side of the Cleddau Valley. South of Leweston these beds are seemingly much affected by strike-faulting; westwards, however, although badly exposed, this outcrop appears to be more or less continuous to Roch. It is possible, through lack of exposure and similarity of weathered products, that a certain amount of Brunel Beds has been included in their mapped outcrop. Igneous rocks, clearly of a keratophyric nature, are exposed in the large quarry at New Inn, north of Camrose.[1] On the south they are consistently bounded by a strip of *Tetragraptus* Shales, as in the Spittal-Tunnel section.

(c) The *Tetragraptus* Beds.

East of the Cleddau Valley.

(1) The Brunel Beds.—The outcrop of the Brunel Beds can be followed from the good exposures of the Cleddau Valley (p. 526) up the valley of the Spittal Brook for about a mile, to the neighbourhood of Golden Hill and Triffleton, where a number of exposures close together combine to yield a fairly complete section through the group. The lowest beds and their downward passage into the Trefgarn Andesitic Series are seen in a sunken lane on the west side of Spittal Common, south of Golden Hill. The transition from the Andesitic Series is so complete that it is difficult to determine to which group some of the beds should be referred. The dip is here steadily northwards at 40°. As we descend the lane from the south the hard flinty andesitic ashes are seen to pass up into beds which are softer, and weather to the colour of yellow ochre. A sandy character gradually becomes more pronounced in these yellow-weathering beds; and black streaks and lenticles of shaly material make their appearance. These shale-lenticles become more important upwards in the succession, and soon the strata pass into dark-blue shales, but slightly sandy, which might easily be taken for typical *Extensus* Shales. These shales are seen at the junction of the lane with the Triffleton road. A little higher up in the sequence the shales become more sandy, and pass into mottled, shaly, yellow-weathering sandstones typical of the Brunel Group, and exposed on both sides of the Spittal Brook between Trefgarn and Spittal Corn Mill.

As will be seen from the map (Pl. XL), a fault that passes immediately east of these localities, and up the eastern side of Spittal Common, introduces a block of country in which the strike is north to south, instead of more or less easterly, and the dip is

[1] 'The Geology of the Country around Haverfordwest' Mem. Geol. Surv. 1914, pp. 21, 22.

gently and steadily eastwards. This fault causes a partial repetition of the outcrop of the Brunel Beds, which here cover a considerable area around Golden Hill and Triffleton, owing to their low dip. The beds are associated with a band of flinty, banded, rhyolitic ash, 15 to 20 feet thick, which crosses the road at Golden Hill, strikes across the Spittal Brook, and proceeds diagonally up a tributary valley to the north. Its uninterrupted course across the two valleys shows that neither of these valleys at this locality follows any fault-line. A little farther north the band is thrown from the western to the eastern side of the tributary valley, by an east-and-west fault, and once again strikes diagonally across the valley towards the farm of Martinique, where it is finally cut out by a powerful east-and-west fault. It is well exposed in crags on each side of the Spittal Brook, and in the tributary valley towards Martinique. This rhyolitic ash appears to have associated with it coarse keratophyric conglomerates, which are exposed in crags and in an overgrown quarry near Martinique, and débris is seen at a number of localities. A microscopic examination of the pebbles and matrix of these conglomerates shows that they have much in common with the volcanic conglomerates that form part of the Trefgarn Andesites, as exposed in the Cleddau Valley and Spittal Tunnel. The pebbles (E 12,585)[1] are microporphyritic keratophyres, in which the phenocrysts are all albite or albite-oligoclase, and in which a fluxion-structure is generally visible. The matrix (E 12,586) consists of fragments of silicified albitic rocks similar to those of the Trefgarn Series, and broken crystals of albite. There is no fragmental quartz of original character. It is reasonable to suppose, from the fact that this conglomerate underlies the main mass of the Brunel Beds, that it corresponds to the conglomerate that marks the top of the Trefgarn Andesites in the Cleddau Valley. But the detailed mapping suggests the possibility that the rhyolitic ash and conglomerate of Golden Hill and Martinique occur a little way up in the Brunel Beds, and not actually at their base. On account of this uncertainty, small portions of the map in this neighbourhood have been left uncoloured.

Stratigraphically above the band of ash and conglomerate comes the main mass of the Brunel Beds, well seen in a quarry in the river-bank below Triffleton Farm. About 50 feet of strata are visible in the quarry where the beds dip a little north of east at 15°. They consist of the usual mottled, impure, ashy green-grey, yellow-weathering sandstone. The mottling is due to the numerous irregular streaks and small lenticles of shaly material, and the strata evidently correspond to those of Brunel's Cutting in the Cleddau Valley. They yielded to us numerous Orthids, seemingly belonging to two species, also *Callograptus* sp., and an *Orthoceras*. A bed in which the argillaceous and arenaceous material were more regularly interbanded, yielded an extensiform graptolite.

[1] These numbers refer to registered specimens in the Geological Survey Collections.

These strata strike northwards up and diagonally across the above-mentioned tributary valley, where they are exposed at Trefgarn Mill and dip eastwards off the rhyolitic ash-band. Higher beds of the group are not so well exposed, but are seen at intervals in the lanes and hedges around Triffleton, where they seem to retain the lithological character of the beds of the large quarry. Upwards they become less sandy, and appear to pass rather gradually into normal *Tetragraptus* Shales.

Faulting causes the Triffleton rhyolite-band to re-appear in the northern bank of the Spittal Brook at Hook Rock, but beds other than the rhyolitic ash are not exposed.

Except for the crag of Hook Rock the country is flat and drift-covered.

(2) The *Tetragraptus* Shales.—Beds referable to the *Tetragraptus* Shales occupy a considerable area up the valley of the Spittal Brook towards Ambleston and Wallis. They consist of the usual dark-blue shales, and are exposed at a number of quarries in the banks of the brook. They are intensely cleaved, and are much affected by minor folding as seen from the varying dips. Fossils are scarce, possibly owing to the intense cleavage; extensiform graptolites were obtained from a small quarry in the southern bank of the Spittal Brook, about half a mile south-west of Wallis.

Downwards the *Tetragraptus* Shales appear to pass into the Brunel Beds. No one exposure shows an actual junction, or a complete passage; but observations at three distinct localities (namely Churchland, Hook, and Nolton) all agree in suggesting that the passage is one of transition.

Upwards the *Tetragraptus* Beds probably pass into the shales of the Sealyham Group; but the exact relations of the two groups are obscured by strike-faulting and by lack of exposure in the drift-covered ground between Rinaston and Ambleston, where the two groups are in geographical contact one with the other.

Tetragraptus Beds west of the Cleddau.

West of the Cleddau the main outcrop of the Brunel Beds as exposed in the old cuttings cannot be traced far, for the rocks (after crossing the valley) turn northwards with the andesites, and strike towards the Roch Rhyolites of Great Trefgarn Mountain. The lowest beds are possibly last seen in the yard of Mountjoy Farm close to the rhyolites of Poll Carn, where grey ashy grits and andesitic conglomerate probably mark the upper limit of the Trefgarn Andesitic Series.

It is possible that along the southern outcrop of the Trefgarn Andesitic Series, between Leweston and Roch, some Brunel Beds have been mapped with the volcanic rocks. The country is badly exposed, and both series of rock weather down to the same ochreous soil.

The *Tetragraptus* Shales form a narrow faulted belt between

Trefgarn Bridge and Roch. They are apparently thrust over higher Ordovician rocks on the south, and have the Andesitic Series as their northern boundary. Their course and fossil contents have already been described in the Geological Survey Memoirs dealing with the districts of Haverfordwest and Milford.

(*d*) The Sealyham Group.

(1) The Sealyham or Wolf's Castle Shales.—The Sealyham Shales occupy a considerable extent of ground in the north-eastern part of the area, and are well seen in the lower part of the Sealy Valley. They consist of dark-blue shales all highly cleaved, with several intercalated thin ashy bands that produce small features within the shale outcrop, as, for example, above the main road at Wolf's Castle. The general dip is north-westwards beneath the Sealyham keratophyres, but the beds are affected by a number of minor folds. These are not often visible, owing to the intense cleavage; but, at a roadside exposure 250 yards north of Sealyham Lodge, where the bedding is made visible by some felsitic ashy bands, the beds are thrown into a sharp overfold, the axial plane of which dips northwards at 70°.

The lithology of the shales agrees in many respects with that of the *Bifidus* Beds of other districts; but, despite careful search, most of the exposures examined failed to yield any trace of fossils, and the only fossils obtained anywhere were some extensiform graptolites from a point on the main road 500 yards north of Wolf's Castle, immediately north of the point where a road branches off to Sealyham Quarries. It is certain that the shales belong either to the *Tetragraptus* or to the *Bifidus* Beds, or perhaps in part to both groups; but, in view of the lack of precision, it seems necessary to apply to them a distinctive name, even if only for the time being. The lack of fossils is all the more unfortunate, since the beds are succeeded by a thick volcanic series, the age of which can at present only be fixed approximately.

It will be seen from the map that the Wolf's Castle Shales pass northwards under the Sealyham keratophyric group; on the west they are brought by the Pwll-Strodyr Fault against the Ford Beds (p. 528), and on the south they are faulted against the Nant-y-Coy Beds of The Barch. Eastwards their exact relation to the *Tetragraptus* Shales of the Spittal-Brook outcrop is uncertain, owing, as already mentioned, to strike-faulting and to the extensive drift cover.

(2) The Sealyham keratophyric series.—The Sealyham or Wolf's Castle Shales pass north-westwards under a thick series of keratophyric rocks that are interbedded with at least one important slate-band, in which is situated the now abandoned Sealyham slate-quarry. The rocks below this slate-band are mainly a thick flow, or series of flows, with overlying ashes; those above the slate-band are mainly massive ashes with some

lavas, and probably a number of intercalated thin slaty bands. The various beds strike diagonally across the Sealy Valley in such wise that the succession is fairly well displayed in the numerous exposures along the stream and in the steep valley-sides. Folding and strike-faulting render any valuation of the total thickness a matter of great uncertainty; but a low estimate would be 600 to 700 feet.

The lowest important band in the volcanic series is a thick keratophyre, or group of keratophyres, exposed east and west of Brynhyfrid, and is readily recognizable by reason of a distinctive brecciation which is developed to a varying degree at almost every locality where the rocks are exposed. The rock itself is greenish porphyritic, vesicular keratophyre, in which the characteristic brecciation is due to the frequent presence of irregular veins and patches of cherty material or of vein-quartz. When the patches or veins are of large size they are essentially cherty; but, as they diminish in size, they become increasingly quartzose, until eventually they are represented by pure white quartz. The larger patches appear to represent muddy material caught up in the lava, altered, and more or less completely silicified. A closely similar brecciation has been described as occurring in the Abercastle keratophyres, which are quite probably on the same horizon as the Sealyham keratophyres.[1] Sections of these rocks (E 12,587) show that they are microporphyritic keratophyres, exhibiting small rectangular and quadrate phenocrysts of albite and albite-oligoclase in a microlithic albitic matrix with chloritized base. They show slight local fluxion-banding, and also betray signs of silicification. They differ from the Trefgarn Andesites in the general absence of recognizable ferromagnesian constituents, and thus they appear to have been essentially felspathic in character.

This main flow or group of flows can be traced from the eastern bank of the Sealy River eastwards to Garn Turne Rocks, where it forms a conspicuous tor. It has furnished a large amount of débris, which has been spread southwards by glaciation over the shale country to such an extent as frequently to mask completely the true character of the ground. East of Garn Turne Rocks the band is faulted out; and similarly, on the west, it appears to terminate against a fault, for it does not pass through Wolf's Castle Village.

Above this brecciated andesite comes a small thickness of andesitic ashes, some porphyritic, others more flinty and fine-grained, with associated ashy slates. These ashy beds are overlain by a slate-band, about 60 feet thick, exposed in Sealyham slate-quarry. The slate is fairly dark blue, and is indistinguishable from the main mass of slates which underlie the volcanic rocks. No fossils have been obtained.

This slate-band is succeeded by a thick series of volcanic rocks,

[1] A. H. Cox, 'The Geology of the District between Abereiddy & Abercastle' Q. J. G. S. vol. lxxi (1915–16) p. 308.

readily distinguishable from those below in being mainly pyroclastic. They consist for the greater part of massive felspathic ashes, together with some subordinate flows. One of the lavas, at a locality just outside the northern boundary of the map, exhibits a crude pillow-structure. The brecciation shown by the Sealyham keratophyres is probably related to the pillow-structure so well-known in many basic lavas. The brecciation seems to take place in lavas that are not sufficiently basic to develop a pillow-structure.

A succession of hollows roughly parallel to the strike suggests the intercalation of softer, possibly slaty strata, with the ashes; and débris obtained from excavations near Sealyham House proved the occurrence of a fairly thick slate-band just below the highest ash. The highest ash-band is well-exposed at Sealyham Rocks, immediately north of the area shown on the map, and what may be the same band is visible in a quarry on the main road north of Wolf's Castle. This ash is fine-grained and flinty, with indications of lamination on its weathered surface. It differs from most of the ashes below in being non-porphyritic, and it bears a strong resemblance to the *Bifidus* Ashes as developed in many areas in South Wales.

The area north of the outcrop of this volcanic series has not yet been examined. It would appear that the volcanic rocks are succeeded by a thick series of shales; but it is not clear at present whether this shale-series is in its normal position, or what is its exact age.

The age of the Sealyham keratophyres is obviously dependent on the age of the underlying Wolf's Castle Shales. Unfortunately, these are very unfossiliferous, as already mentioned, so that their exact horizon is uncertain. They have only yielded a few extensiform graptolites, from which it would appear that the volcanic rocks must either occupy a high level in the *Tetragraptus* Shales, or some level in the *Bifidus* Shales which should normally succeed the *Tetragraptus* Shales. Comparison with similar volcanic types at Abercastle (p. 545) suggests a *Tetragraptus* age.

Other Keratophyre Outcrops.

There are in the district two other outcrops of keratophyric rocks which probably belong to the Sealyham Group, but are isolated from the main outcrop by faulting.

The Rinaston outcrop.—One of these outcrops is immediately north of Rinaston, where débris is abundant in many of the fields and the weathered rocks are visible in sand-pits on the main road 300 to 400 yards north of Rinaston Farm. The sand-pits are 10 feet or more in depth, but even at the bottom the rock is in the condition of loose sand, and so badly weathered that it is hardly recognizable as an igneous rock. The original rock, however, had suffered brecciation of the type that is so characteristic of the lower lavas of the Sealyham Group, and this brecciation still shows as veins and patches of dark fine-grained material

in the sand. These veins give the clue to the nature of the rock, and their distribution shows that the mass is *in situ*. Sand-pits in weathered igneous rocks of various types, granites, etc. are not uncommon in Pembrokeshire, and the materials are perhaps accounted for as the products of pre-Glacial weathering which have escaped erosion and dispersion during the Glacial Period, owing to their position on the lee side of small hills.

In general, the rocks of this Rinaston outcrop are badly and insufficiently exposed; thus, their exact boundaries and their relations to neighbouring sediments are very obscure. The keratophyres make a small and almost circular hill, and are apparently surrounded on all sides by sedimentary rocks; but the boundaries are mostly faults. On the north they are certainly separated by shales (Sealyham Shales) from the main keratophyres of Sealyham and Garn Turne. Eastwards they disappear under the drift-covered ground towards Ambleston, and they seem to be separated by *Tetragraptus* Shales from the Ambleston keratophyres (described below). Southwards they come into contact with badly-weathered rocks referable to the Brunel Beds.

As the result of lack of exposures and of the obvious extensive faulting, there is no direct evidence as to the age and horizon of these Rinaston andesites. But the characteristic brecciation observed in the rocks at the sand-pits suggests that they are counterparts of the Sealyham–Garn Turne keratophyres. Their occurrence at Rinaston is most readily explained on the supposition that they represent a continuation of the Garn Turne band which has been bent in a north-and-south direction in agreement with the north-to-south strike of country on the south, and that the nose of the flexure (on this interpretation, anticlinal) has been replaced by faults that introduce a strip of the underlying shales between the two igneous outcrops.

The Ambleston outcrop.—Another isolated outcrop of keratophyric rocks occurs between Ambleston and Wallis. The rocks are well exposed in a series of crags above the Spittal Brook, where they are seen to consist of compact, greenish-grey, micro-porphyritic lavas and ashes, with a dip of 20° to 25° northwards.

These rocks appear to form a boat-shaped mass that might be interpreted as forming the core of a syncline. But all the boundaries are probably faults, except possibly the southern margin, where the beds may rest conformably upon the underlying *Tetragraptus* Shales. The outcrop cannot be followed westwards into the village of Ambleston, aud it is separated from the Rinaston outcrop by a drift-filled depression, which, from the occasional exposures, seems to be situated entirely on *Tetragraptus* Shales.

On account of their geographical association with *Tetragraptus* Shales, it is supposed that the keratophyric rocks of Ambleston are also counterparts of the Sealyham keratophyres, and exist as a faulted lenticle.

A section of one of the representative masses of these rocks shows that the rock (E 12,584) is of rather unusual character. It is a microporphyritic keratophyre with acid plagioclase-phenocrysts in a microlithic matrix of albite-oligoclase. In addition, however, it contains moderately large decomposed phenocrysts of hornblende. A similar rock occurs at Croes Wen north-east of Solva, but its relations to the surrounding sediments are as yet unknown.

The exposures at Wallis furnish a splendid example of the southward migration of great masses of boulders, pushed off the crags by glaciation from the north. The valley of the Spittal Brook is almost choked with such boulders, and they completely cover even the southern flanks of the valley. This southern flank was accordingly shown as an outcrop of igneous rock on the old geological maps, but recent excavations and small quarries have shown that this ground is really occupied by *Tetragraptus* Shales. It furnishes an object-lesson in the necessity for caution in this district, in regarding even extensive masses of blocks of igneous material as indicative of an outcrop, especially if the masses are anywhere south of a known outcrop of similar material.

(*e*) The Roch Rhyolitic Series.

The Roch Rhyolitic Series forms a more or less continuous ridge from the Trefgarn Rocks to Roch Castle. It is divisible, as in the Cleddau Valley (p. 527), into two main groups: a mass of flinty bluish rhyolites and ashes, and a higher group of bedded and less siliceous rhyolitic ashes (Nant-y-Coy Beds). The flinty rocks do not form a continuous band, but appear at intervals, sometimes at the base and sometimes towards the middle of the outcrop. The flinty rocks of Trefgarn Rocks range up into Great Trefgarn Mountain, and form the prominent crags of Maidens Castle and Poll Carn. Here their upper boundary turns into the southern boundary-fault, and the whole of the outcrop, thence through Leweston Mountain to Plumstone, is occupied by Nant-y-Coy Beds. An old quarry at the western end of Great Trefgarn Mountain shows these beds to be striped, pale blue-grey, pyritous shales, dipping east of south at 30°. The flinty rocks appear to make a small outcrop on Plumstone Mountain, and are answerable for the landmark known as Plumstone Rock. A similar detached boat-shaped outcrop occupies the Beacon on Dudwell Mountain, and the final mass is that of Roch, on the crags of which stands the picturesque Castle that forms one of the most noted landmarks of Pembrokeshire. Northward, these flinty lavas and ashes are invariably followed by Nant-y-Coy Beds; but on Cuffern Mountain there is evidence of a lower member of the series than is exposed elsewhere along the outcrop. Some old quarries north of Cuffern House show a considerable thickness of rhyolitic breccia in which the pale rhyolite-fragments are markedly contrasted with a dark-grey matrix. This breccia can be traced along the

south side of Cuffern and Dudwell Mountains: that is to say, where the outcrop of the rhyolitic series as a whole appears to be the widest. It is probable that these breccias are faulted out in the Cleddau Valley, and that they constitute a group lower than the flinty rhyolites and ashes.

The nature of the boundaries of the Rhyolitic Series between the Cleddau and Roch makes it quite clear that they are faults; but actual junctions with adjacent formations are in no instance exposed.

Age of the Roch Rhyolitic Series.

The age of two of the three volcanic series in the area under description is fixed either definitely or approximately. The Trefgarn Andesitic Series is definitely proved to occupy a low horizon in the Arenig, since it passes conformably upwards into *Tetragraptus* Beds. The Sealyham Keratophyric Series is underlain by shales that contain extensiform graptolites, and is therefore at a high level in the *Tetragraptus* Beds or low down in the succeeding *Bifidus* Zone. But the age of the Roch Rhyolitic Series cannot be settled by direct evidence, and it seems most probable that this series is of pre-Cambrian age. When we commenced the examination of the unsurveyed portion of the district, we were inclined to think that the rhyolitic series was of Arenig age, and that it formed an upper part of the Trefgarn Volcanic Series.[1] This was a natural inference, in view of the following facts:—

(i) the proved Arenig age of the andesites;
(ii) the close association of andesitic and rhyolitic groups over many miles of country;
(iii) fossiliferous Arenig rocks in the Cleddau Valley dip consistently towards the rhyolitic series, which appeared therefore to be part of an ascending sequence.

But, as a wider area was examined, the difficulties of assigning an Arenig age to these rhyolites became manifest.

Both the southern and the northern boundaries of the rhyolitic outcrop are clearly determined by strike-faults. Along their southern boundary the rhyolites are faulted in turn against *Tetragraptus* Shales, against an ascending succession of the Brunel (Lower *Tetragraptus*) Beds, and against *Lingula* Flags, the newer beds being on the east as the result of an eastward pitch. Along their northern boundary the rhyolites are faulted in turn against Sealyham Shales (*Extensus* or *Bifidus* Beds), Ford Beds (uncertain age, Middle or Upper Cambrian), and against the Cambrian and pre-Cambrian Rocks of the Hayscastle mass. Here again, it would appear that an eastward pitch causes the newer rocks to appear on the east. For, on the west, the rhyolites are interposed between *Lingula* Flags and the pre-Cambrian, while on the east they are interposed between various divisions of the

[1] 'The Geology of the Country around Milford' Mem. Geol. Surv. 1916, p. 39.

Arenig Series. At first sight, it would seem that the succession is more nearly complete towards the east in the neighbourhood of the Cleddau Valley. There the rhyolites follow on an ascending succession of Brunel Beds, and, although the junction is clearly faulted, there would still be grounds for assuming that the true horizon of the rhyolites is at the top of the Brunel Beds, or perhaps at some higher horizon in the Arenig-Llanvirn Series.

As the survey of the ground on the east continued the structure there revealed negatived the supposition that the true place of the rhyolites is at the top of the Brunel Beds: for, at three different localities in the valley of the Spittal Brook (namely Nolton, Churchland, and Hook), there appears to be a fairly complete sequence from the Brunel Beds into the *Tetragraptus* Shales. At Churchland there is no sign of any rhyolitic beds at all. At Hook there is a small outcrop of rhyolite, which can be correlated with the thin rhyolite-band seen in the Brunel Beds south-west of Triffleton, and thus does not in any way compare, as regards either position or magnitude, with the development of the Roch Series on Great and Little Trefgarn Mountains. At Nolton there is much rhyolite-débris associated with the *Tetragraptus* Shales. It is possible that this may represent another thin rhyolite-band comparable with, but at a slightly different horizon from, that of the Golden Hill band; but, more probably, it is glacially transported material from the crags of the main rhyolite of Little Trefgarn Mountain. A diminishing trail can be followed southwards all the way from Little Trefgarn to Nolton. The evidence at the three localities is fairly conclusive that there is no thick rhyolitic series between the Brunel Beds and the *Tetragraptus* Shales. Further, it is difficult to imagine that the Roch Rhyolites, after maintaining a considerable thickness over the 7 miles from Roch to Little Trefgarn, should suddenly die out in the 1 mile between Little Trefgarn and the Spittal Brook.

Even if such a rapid attenuation were possible for the rhyolites proper, it is yet more unlikely that the thick pyroclastic series of the Nant-y-Coy Beds, which is always associated with the rhyolites and is present in force on Little Trefgarn, should suffer so rapid an attenuation as to cause it to disappear completely in a single mile. It is further unlikely that at all three localities the rhyolitic rocks are cut out by strike-faults, since there is no sign of such faults in the neighbouring rocks, in which dips are constant, and the sequence appears to be complete and undisturbed to any noteworthy extent. The inference is that the Roch Rhyolitic Series does not normally occur at the top of the Brunel Beds. Further, there is no sign of any rhyolitic rocks in the wide outcrop of the thick shale series which succeeds the Brunel Beds and includes the *Tetragraptus* Shales of Spittal Brook and Wallis, and the Wolf's Castle Shales of the Sealyham area. We conclude, therefore, that the field-evidence is against the view that the Roch Rhyolites occupy any horizon in the Arenig Series.

In comparison with developments of the Ordovician System in other parts of Pembrokeshire, the next horizon at which a rhyolitic series might be expected is near the top of the *Bifidus* Beds, at which stratigraphical position occur the widespread rhyolitic rocks of the North Pembrokeshire coast (Ramsey Island, Abereiddy Bay, Fishguard, etc.). But structural considerations render it extremely unlikely that the Roch Rhyolites occur high in the *Bifidus* Series. Their geographical association is with formations ranging in age from early Arenig to pre-Cambrian. To postulate a *Bifidus* age for the rhyolites would mean that a great strip of newer rocks has been faulted down into an extensive tract of country, otherwise consistently occupied by older formations. The nearest points to the Roch and Trefgarn outcrop at which the *Bifidus* rhyolitic series occurs, are Fishguard, 8 miles away to the north, and the western extremity of the Prescelly Mountains, 5 miles away to the east. Since the nearest rhyolite-outcrops are so distant, and there are no occurrences of rhyolite in the intervening shale-country, it is most unlikely that the *Bifidus* rhyolites should suddenly be introduced among the older beds of the Trefgarn district. We consider, therefore, that the possibility of a Llanvirnian age for the Roch Rhyolites may be disregarded.

If the Roch Rhyolites are neither of Arenig nor of Llanvirn age, it is improbable that they are of Ordovician age at all, and therefore the likelihood of their being pre-Cambrian must be borne in mind. Several considerations support this latter hypothesis. Along the central stretch of its outcrop the rhyolitic series is in actual contact with the pre-Cambrian rocks of the Hayscastle mass, and the upper part of these pre-Cambrian rocks consists of rhyolitic lavas and tuffs. There is certainly a distinct resemblance between the Nant-y-Coy Beds and the Ramsey-Sound Beds that constitute the highest visible pre-Cambrian rocks of the St. David's district. On the assumption that the Roch Rhyolites are pre-Cambrian, their geographical position between *Lingula* Flags and the Hayscastle pre-Cambrian mass is readily explained. Also the structures which have brought about the geographical sequence of *Lingula* Flags, Roch Rhyolites, Nant-y-Coy Beds, Hayscastle pre-Cambrian, would represent a natural continuation of the very characteristic structures in the ground immediately to the south, where the country consists of a series of strips with the strata in each strip dipping northwards, each block being bounded on its northern side by a fault that brings up older strata. Accordingly, there is a strong case in favour of the Roch Series being of pre-Cambrian age, and possibly an equivalent of part of the Pebidian Series of St. David's.

It is somewhat difficult to compare the Roch Rhyolites with any of the known pre-Cambrian rocks of Pembrokeshire; but the greatest resemblances are exhibited by the members of the Rhindaston and Gignog groups of the Hayscastle district.[1]

[1] H. H. Thomas & O. T. Jones, Q. J. G. S. vol. lxviii (1912) pp. 385–87.

The main difference is that the Rhindaston Rhyolites are essentially quartz-bearing, small porphyritic crystals of quartz being visible to the unaided eye; while phenocrysts of quartz are usually absent from the rocks of the Roch Series. It must, of course, be borne in mind that the Rhindaston and Gignog group was invaded by quartz-porphyrics and granites of Dimetian age, but so far no intrusion of any kind has been observed to cut the Roch Series. This may indicate, as Hicks originally suggested, that the Roch Series is later than any of the neighbouring pre-Cambrian masses with which we are acquainted, and referable therefore to a different group.

V. The Geological Structure.

The general disposition of the rocks of this district, as indicated on the map (Pl. XL), shows the usual Western Welsh strike of east-north-east to west-south-west to be dominant. The structure of the area as a whole is largely controlled by the great anticline that brings up the pre-Cambrian mass of Hayscastle on the north and by a subsidiary anticline on the south, of which the northern thrust-limb accounts for the position of the *Lingula* Flags of Trefgarn and Lady's Cross.

The northward-dipping succession visible in the Trefgarn Bridge and Spittal-Tunnel section (p. 529), where older beds appear towards the north in order of increasing age, must point to the successive southward thrusting of the formations present in the northern limb of an anticline. This structure holds good for the whole belt of country lying south of the southern andesitic outcrop between Trefgarn Bridge and Roch.

The belt of *Lingula* Flags is in the nature of a horst, and, as we proceed northwards, it is obvious that the andesites and Brunel Beds of the Cleddau Valley form the northern part of another anticline that has been thrust over the *Lingula* Flags with the almost complete sacrifice of its southern limb. A similar anticlinal structure is also suggested by the Roch and Nant-y-Coy rocks—the southern limb and the syncline that should exist between them and the Brunel Beds being represented by an overthrust or fault.

The pitch of these major folds changes its direction on either side of a roughly north-and-south line drawn through the centre of the district. On the east the structures pitch eastwards and *vice versa*, so that anticlinal outcrops of the older rocks narrow in both directions and finally disappear. East of the Cleddau Valley the eastward pitch of the folds is clearly brought out, as around the eastern portion of the Hayscastle Anticline, by a marked change in the strike of certain beds to north-and-south.

A disturbance of an entirely different type is the great north-west line of faulting which has been termed the Pwll-Strodyr Fault. This fault pursues a gently curving course from Pwll Strodyr on the northern coast, and enters the north-east of the area now being considered, where it forms the eastern boundary of

the Hayscastle mass, and throws the Sealyham Group against the older rocks. A little farther south the fault either dies away, or is deflected by, or into, one of the east-and-west strike-faults: for the outcrop of the Nant-y-Coy Beds crosses the fault-line without displacement. Such a deflection is rather unexpected, since along other parts of its course the Pwll-Strodyr Fault seems itself to traverse and displace all the east-and-west structures. It is true that a little farther south the line of faulting is continued by some faults of small throw; but their effects are not in any way comparable with the great disturbance along the Pwll-Strodyr Fault proper. Further, it is certain that no fault of any magnitude crosses the outcrop of the Brunel Beds of Spittal Brook. The visible course of the Pwll-Strodyr Fault from the coast to the outcrop of the Nant-y-Coy Beds at Little Trefgarn is about 8 miles, so that the sudden disappearance is somewhat remarkable.

The major folds and faults that affect this district are, as was pointed out in connexion with the Hayscastle district, most probably of pre-Carboniferous age; for, in the district immediately to the west the Upper Carboniferous rocks transgress all the other Palæozoic formations, and are themselves unaffected by the intense east-and-west disturbances that have affected the older rocks.

VI. Correlation.

(*a*) South Wales.—No other area in South Wales shows a sequence identical with that of the Trefgarn district, for the reason that the Trefgarn Andesites are of a type almost unique in Wales. Accordingly, for purposes of correlation, it will be convenient to consider each group in turn and discuss its probable equivalents elsewhere, rather than to describe variations of the whole sequence as exhibited by a number of districts.

The age of the Roch Rhyolitic Series, including the Roch Rhyolites and the Nant-y-Coy Beds, and their possible equivalents in other areas has already been discussed (p. 540).

The Trefgarn Andesites occupy a position at or near the base of the Arenig Series, and have no certain equivalents in South Wales, nor are their petrological characters represented elsewhere. Evidence of volcanic activity on approximately the same horizon may be drawn from Llangynog[1] in Carmarthenshire and from Henllan Amgoed[2] on the borders of Carmarthenshire and Pembrokeshire. The volcanic series of Skomer Island,[3] although probably of Arenig age, cannot be directly dated, nor is the erupted material in any way comparable. The rocks at Llangynog which are associated with Llanvirn and Arenig sediments certainly have points in common

[1] T. C. Cantrill & H. H. Thomas, 'The Igneous & Associated Sedimentary Rocks of Llangynog' Q. J. G. S. vol. lxii (1906) p. 223.

[2] H. H. Thomas, in 'The Geology of the Country around Haverfordwest' Mem. Geol. Surv. 1914, p. 17.

[3] *Id.*, 'The Skomer Volcanic Series' Q. J. G. S. vol. lxvii (1911) p. 175.

with the Trefgarn Andesites. Moreover, it is probable, though not capable of proof, that they occur on approximately the same horizon. At Henllan Amgoed the lowest rocks exposed are Arenig sediments that carry a *Callograptus* fauna, and are associated with ashes of andesitic or keratophyric composition. Possibly the Henllan Anticline has not been sufficiently eroded to expose the volcanic horizon of Trefgarn, but only the equivalents of the Brunel Beds.

The absence of any trace of volcanic rocks at all the other numerous localities in Pembrokeshire where *Lingula* Flags and Arenig Beds are in contact is not wholly explained by the fact that the junctions are usually faults. The true explanation is probably that the Arenig in Pembrokeshire is unconformable to the rocks below and that the unconformity was attended by overlap among the lower members of the Arenig Series. Evidence for this unconformity is found in the invariable absence of true Tremadoc rocks, in the local distribution of the Trefgarn Andesites which occur at or near the base of the Series, and in the variable thickness and development of the overlying Brunel Beds or their equivalents in other localities (see below). It seems highly probable that there must have been overlapping among these shallow-water sandy strata, and that usually they trangressed directly on to Upper Cambrian rocks with the possible obliteration of the older volcanic series.

The sandy Brunel Beds have their nearest equivalents in the Abercastle and Porth Gain Beds of the northern coast.[1] The lithology, the fauna so far as known, and the relation to the overlying *Tetragraptus* Shales, are all identical in the two areas. The supposed Tremadoc of Hicks on Ramsey Island [2] and in Whitesand Bay [3] has been shown to be equivalent to the sandy Arenig Beds of North Pembrokeshire.

In districts farther east the *Tetragraptus* Shales are underlain by a series of mudstones and grits to which the name *Ogygia-selwyni* Beds has been applied. This lower series is well developed in the Carmarthen and Whitland districts,[4] more especially in the anticlinal area of Henllan Amgoed, first described by the late T. Roberts. There is little doubt that the Brunel Beds are their equivalents as regards horizon, and the ashy character of some of the lowest beds at Henllan Amgoed furnishes confirmation of this view.

The *Tetragraptus* Shales are so well known, and cover such large areas in South Wales that their correlation need not be discussed.

The exact position of the Sealyham keratophyres is unfortunately

[1] A. H. Cox, 'Geology of the District between Abereiddy & Abercastle' Q. J. G. S. vol. lxxi (1915–16) p. 283.

[2] J. Pringle, Geol. Mag. 1911, p. 556.

[3] A. H. Cox, Q. J. G. S. vol. lxxi (1915–16) p. 290.

[4] For details of the Arenig Succession in the Whitland district, see 'The Geology of the Country around Haverfordwest' Mem. Geol. Surv. 1914, p. 14.

somewhat uncertain. It has, however, been shown that they must either occupy a position high up in the *Tetragraptus* Shales, or somewhere in the succeeding *Bifidus* Beds. In neighbouring areas volcanic rocks are represented by the keratophyres at Abercastle near the top of the *Tetragraptus* Shales,[1] and by rhyolites at Llanrian, Fishguard, and elsewhere which appear near the top of the *Bifidus* Zone. Some of the Sealyham keratophyres, in particular those of the lower mass which forms Garn Turne, etc., resemble the Abercastle keratophyres very closely. The curious brecciation noticeable in the rocks of both districts is especially striking. The rocks are again similar, in that the Abercastle keratophyres are followed after a short interval by *Bifidus* Ash, and the Sealyham rocks are also followed by an ash-band of which the lithology compares closely with that of the *Bifidus* Ash of many South Welsh localities. The most noteworthy difference between the volcanic series in the two areas is the considerable development of pyroclastic rocks at Sealyham, whereas lavas alone are represented at Abercastle. Despite this difference, it appears probable that the Sealyham rocks are to be correlated with the Abercastle keratophyres. The re-investigation of the intervening country is not quite complete; but it would seem that the Abercastle keratophyres extend as far as Priskilly Fawr[2] where they end eastwards against the Pwll-Strodyr Fault, only 2 miles north of Sealyham. It is probable that they re-emerge on the east side of the fault as the Sealyham keratophyres.

Considering the sequence as a whole, from the *Lingula* Flags upwards, the Abercastle district offers a closer comparison with Trefgarn than any other district in South Wales, the only essential point of distinction being the absence at Abercastle of any representative of the Trefgarn Andesites.

(*b*) North Wales: Rhobell Fawr.—It is curious that it is necessary to go as far as North Wales, to Rhobell Fawr in the Dolgelley district, in order to obtain the best parallel of the Trefgarn sequence. And a further curious coincidence is that just as the Trefgarn sequence is unique in South Wales, so the Rhobell Fawr sequence is unique in North Wales. We are indebted to the kindness of Mr. A. K. Wells for allowing us to mention some of the results of his re-examination of that area, which he expects to communicate to the Society in the near future. On Rhobell Fawr a series of porphyritic andesites including lavas and tuffs, often purple in colour, rests unconformably upon Upper Cambrian rocks, and is succeeded by arenaceous beds of Arenig age.

These volcanic rocks are purely local in their distribution, and their rapid disappearance is apparently due to overlap by the higher arenaceous strata. The resemblance to the Trefgarn Andesites is thus most pronounced, even to the distinctive

[1] A. H. Cox, Q. J. G. S. vol. lxxi (1915–16) p. 308.
[2] J. V. Elsden, *ibid.* vol. lxi (1905) p. 597.

coloration of the rocks. It is possibly more than a mere coincidence that these two sets of purple andesites and tuffs which are otherwise unique in stratigraphical position, should both be restricted to the south-eastern margin of great domes of older rocks: namely, the Harlech Dome and the Hayscastle mass respectively.

VII. Summary and Conclusions.

The area dealt with in this paper lies in Northern Pembrokeshire, and stretches from Roch on the west, across the valley of the River Cleddau, to Ambleston on the east, a distance of some 9 miles.

The rocks for the greater part strike approximately east and west, and the district is dominated by an east-and-west elevated tract formed of rhyolitic lavas and ashes (Roch Series) that extend from Roch to the gorge of the Cleddau, by way of Cuffern and Plumstone Mountains.

The lower ground on the south and east is occupied by rocks of Upper Cambrian and Lower Ordovician age, and in the latter we have recognized and mapped two distinct volcanic series, to which we have applied the names Trefgarn and Sealyham respectively. The Trefgarn Andesites can be demonstrated to occupy a low position in the Arenig Series; while the Sealyham keratophyric rocks occur on a higher horizon, either at the top of the Arenig, or in the lowest portion of the Llanvirn Series.

The stratigraphical position of the Roch Rhyolitic Series cannot be proved by direct evidence; but the structure of the district and the observed succession of the neighbouring Cambrian and Ordovician rocks strongly suggest a pre-Cambrian age. This series was claimed to be pre-Cambrian by the late Dr. Henry Hicks, and to form part of his Arvonian Group; but he erroneously included the Trefgarn Andesites.

The geological sequence and the continuity of outcrops are much disturbed by strike-faulting.

In conclusion, we wish to express our thanks to Prof. O. T. Jones, who worked with us over the sections in the Cleddau Valley; and one of us (A. H. C.) wishes to acknowledge a grant from the Royal Society which helped to defray part of his expenses connected with the investigation.

EXPLANATION OF PLATE XL.

Geological map of the Roch-Trefgarn-Ambleston district, on the scale of 1 inch to the mile, or 1 : 63,360. [In the reference to Ford Rocks, 'Q. J. G. S. vol. xlviii' should read 'Q. J. G. S. vol. lxviii.'

Discussion.

Mr. J. F. N. Green remarked on the support afforded by this paper to the views of the late Dr. Hicks with regard to the age of the Roch Castle rock, and on the success of that worker in lithological correlation in a most difficult district. He thought that the Authors' determination of the position of the andesitic series might throw light on the curious occurrence of intrusive andesites, resembling lavas in many respects, in the Lower Cambrian and pre-Cambrian west of St. Davids.

The President (Dr. J. W. Evans) drew attention to the interest of the question of the relative age of the late pre-Cambrian eruptives. Those at St. Davids appeared, from Mr. Green's work, to have been separated from the Cambrian by a desert period.

Dr. H. H. Thomas, replying on behalf of the Authors, wished to associate himself with Mr. Green in paying tribute to the work of the late Dr. Hicks, who, although he had committed several errors, had done more than most investigators to place the stratigraphy of the older Palæozoic rocks on a firm footing.

In answer to the President, he stated that, unlike the pre-Cambrian rocks of Hayscastle and Brimaston north of the area described, the Roch Rhyolitic Series was not penetrated by any intrusive masses. This might suggest that, if pre-Cambrian, the Roch series was younger than the pre-Cambrian rocks of the adjoining district.

22. *On an* Olivine-Dacite *in the* Tertiary Volcanic Series *of* Eastern Iceland : *the* Rauthaskritha (Hamarfjord). By Leonard Hawkes, M.Sc., F.G.S. (Read April 9th, 1924.)

[Plates XLI & XLII.]

Contents.

I. Introduction.

The flow of dacite to be described crops out in the face of the cliff bordering the north of Hamarfjord—one of the deep incisions into the Tertiary basalt-plateau of South-Eastern Iceland. A mass of acid rock occurring in a district entirely built up of dark basaltic lavas—it attracts attention by reason of the light colours of its different lithological members, and its unusually abundant scree-formation. It is known as the 'Rauthaskritha', or 'red scree', and has been described by all geologists who have visited the district.

C. W. Paijkull examined this occurrence of 'trachyt', and regarded it as a dyke, giving a diagrammatic section in illustration (2).[1] The dyke is shown more than half a mile thick cutting through the basaltic series, and terminated above by one of the basalts. A glassy facies is observed at the two vertical margins and also on the top. The mass exhibits contorted banding, and is cut by dolerite-dykes which fail to penetrate the overlying basalts. The country-rocks are quite undisturbed, and no suggestion is put forward as to how room was made for this remarkable intrusion. Other writers, Th. Thoroddsen (12) and A. Helland (6), have admitted the intrusive nature of the rock.

After making a detailed examination of this occurrence in the course of three summer visits, I have come to the conclusion that it represents a lava-flow.

The Rocks of the District.

These are regularly bedded plateau-basalts with interbasaltic partings of red lateritic deposits, dipping 5° to 7° westwards. Magnificent sections from 2000 to 3000 feet in height are given

[1] Numerals in parentheses refer to the bibliography, §VI, p. 565.

by the steep valley and fjord walls, and the series is almost exclusively volcanic, sills being rare. Plant-remains found at various horizons in Eastern Iceland indicate a Tertiary age for the lavas; but no base to them has yet been discovered, and the possibility of a Cretaceous age for the lower members cannot be ruled out. The series is pierced by a great number of dolerite-dykes which stand out as walls on the raised-beach platform that provides the habitable part of the Hamarfjord region. With the exception of a few quartz-porphyry and composite dykes the rocks of the district are basic. Some 2 miles distant is the famous locality for zeolites, Teigarhorn in Berufjord. The dykes and fracture-lines have a constant north-north-easterly direction.

II. Field Relations and Origin.

The Rauthaskritha.

The vertical section of the acid mass is that of a rectangle tilted westwards with the basalts. The screes hide the lower part of the cliff; but I was fortunate in discovering basalts underlying the dacite, and the recognition of this base makes the conception of a dyke untenable. The homogeneous magma has, under the various conditions of cooling, given rise to a great variety of rock-types.

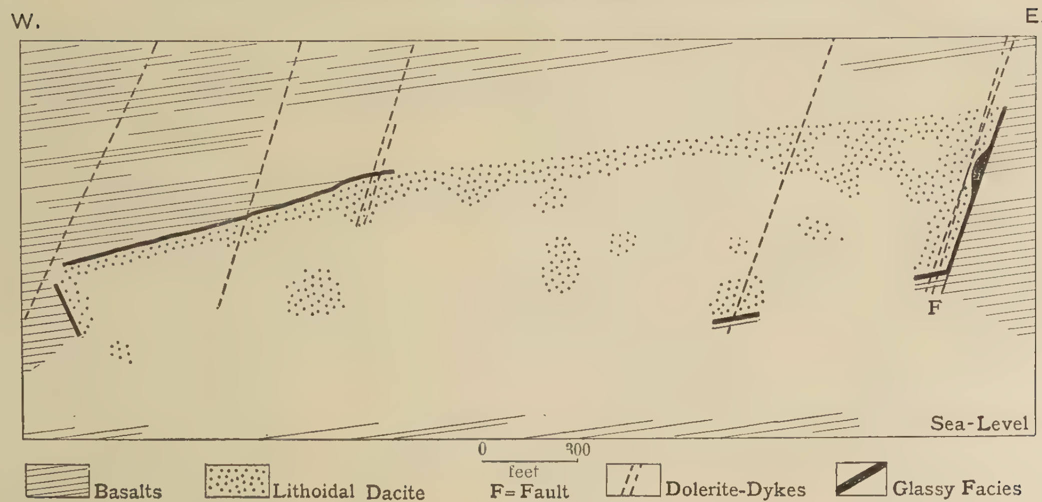
Fig. 1 (p. 551) shows the actual features of the cliff, where not covered by scree. The dacite appears broader at the top, because its vertical boundary-walls are converging towards the observer, and the cliff has a backward slope.

The main mass is a fine-grained rock containing felspar-phenocrysts 2 mm. long. It is grey and compact below, white and porous above. A red colour is developed on weathering, and this is especially notable in the upper eastern exposures. Flow-banding is prominent, and the rock splits readily into plates. Slabs in the screes are often hexagonal, revealing an incipient columnar structure across the parting, although this gives rise to no feature in the cliffs. The banding is even and horizontal in the lower part of the mass; but it becomes contorted higher up, and curves round to stand vertically in places at the top. It is impossible to make out any regular disposition of these bands.

The Peripheral Rocks.

Wherever the contact with the basalts is seen, a glassy facies is present—varying in thickness from 6 to 30 feet—and spherulitic structure is developed in places, especially at the vertical contacts. At the eastern end is a wall of black and green obsidian and pitchstone, 500 feet high, and commonly 6 to 12 feet thick, but swelling out to 30 feet in the middle of the exposure. This glassy rock weathers into rounded and angular masses, giving a conglomeratic and brecciated appearance, and at the base contains

Fig. 1.—*Elevation of the Rauthaskritha cliff.* (See p. 550.)

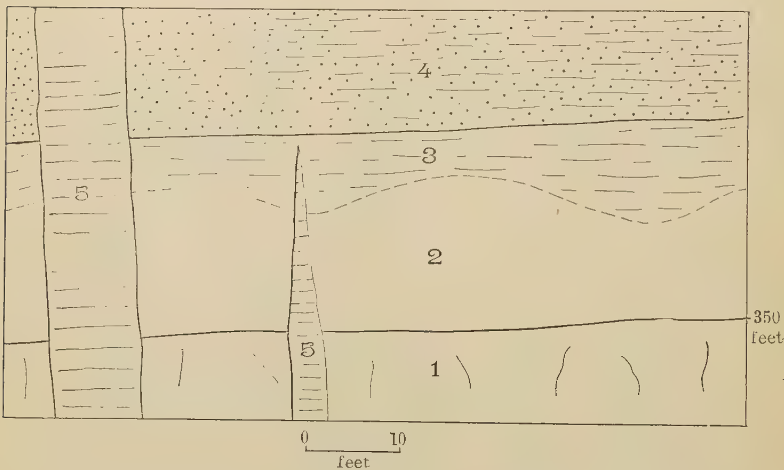


fragments of vesicular basalt up to 1 foot in length. Some of the pitchstone bears scattered spherulites 3 to 5 mm. in diameter; but these bodies may increase to form the whole rock, which is then made up of closely fitting polygons. The larger spherulites are hollow.

At the western boundary is a wall of obsidian averaging 15 feet in thickness, which can be followed for 180 feet. Towards the lithoidal dacite, spherulitic structure is developed and the weathered rock is in places a mass of spheres, some being 3 inches in diameter. This glassy wall is lost in scree above and below (fig. 1, p. 551).

The section (fig. 2) illustrates the occurrence of the basal portion of the mass, as revealed in the eastern part of the scree-slope.

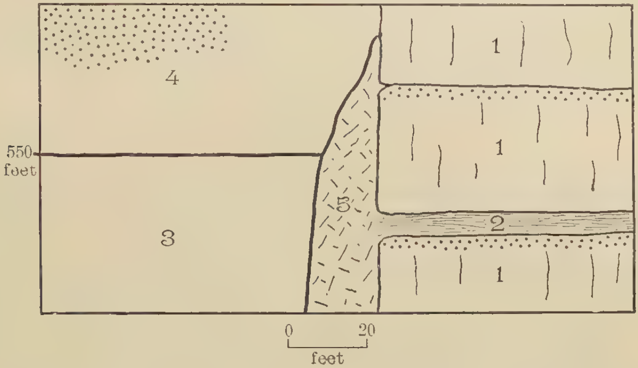
Fig. 2.—*Detail of the base of the dacite.*



1 = Basalt. 2 = Brecciated obsidian. 3 = Banded pitchstone.
4 = Banded dacite. 5 = Dolerite-dyke.

The glassy facies is 20 feet thick, and may be divided into a lower brecciated layer and an upper banded pitchstone, which latter passes gradually upwards, without the development of spherulitic structure, into the regularly banded dacite. The banding is generally horizontal, but dips into the cliff in places, indicating flow on an uneven floor. The junction with the overlying basalts is hidden in the middle and eastern part, and no glassy types were seen *in situ*. The top of the mass gives rise to a broad platform below the cliff-wall of the upper basalts, and one block of obsidian was found here, indicating the former presence of the glassy shell. At the western end obsidian caps the contorted lithoidal rock. It is from 10 to 20 feet thick, and forms the top of the platform here (fig. 4, p. 553).

Fig. 3.—*Detail of the lower eastern corner exposure of dacite.*

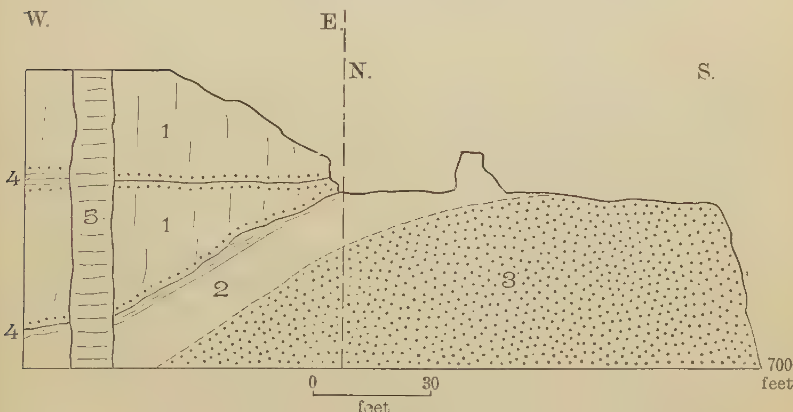


1 = Basalts. 2 = Red parting. 3 = Basalt beneath the acid flow.
4 = Pitchstone and lithoidal dacite above. 5 = Basalt-breccia.

Relationship to the Plateau-Basalt Series.

Two features are notable: the lack of any disturbance, fault, or fold in the adjoining rocks; and the vertical boundaries where the basalts are suddenly cut off by the glassy walls. At the eastern

Fig. 4.—*Relationship of the overlying basalts to the dacite at the eastern end of the upper obsidian exposure.*



1 = Basalts with vesicular upper and lower boundaries. 2 = Glassy facies of dacite. 3 = Lithoidal dacite with contorted banding.
4 = Interbasaltic beds. 5 = Dolerite-dyke.

boundary the individual basalts are vesicular above and below, but not along the vertical contacts. A fault-plane separates these basalts from those underlying the dacite, and there is some

development of breccia here. The western boundary exhibits similar features: the base, however, is hidden by scree.

The relationship of the top of the mass to the overlying basalts, at its western end, is shown in fig. 4 (p. 553). No faults occur in the upper basaltic series, and the way in which the basalt-flows thin out against the dacite is clearly indicated.

Intrusions.

Many dolerite-dykes trending north-north-eastwards pierce the whole series. The dacite is often brecciated in their vicinity, and they pass upwards through the overlying rocks, and do not terminate at the cover as shown in Paijkull's section.

Origin.

The dacite has resulted from the cooling of magma in its present position. This is clear from the presence of a glassy facies at all visible contacts, and there can be little doubt that the obsidian shell was originally continuous. At the eastern contact a thin skin of pitchstone was observed adhering to one of the basalts. The mass cannot have been faulted down.

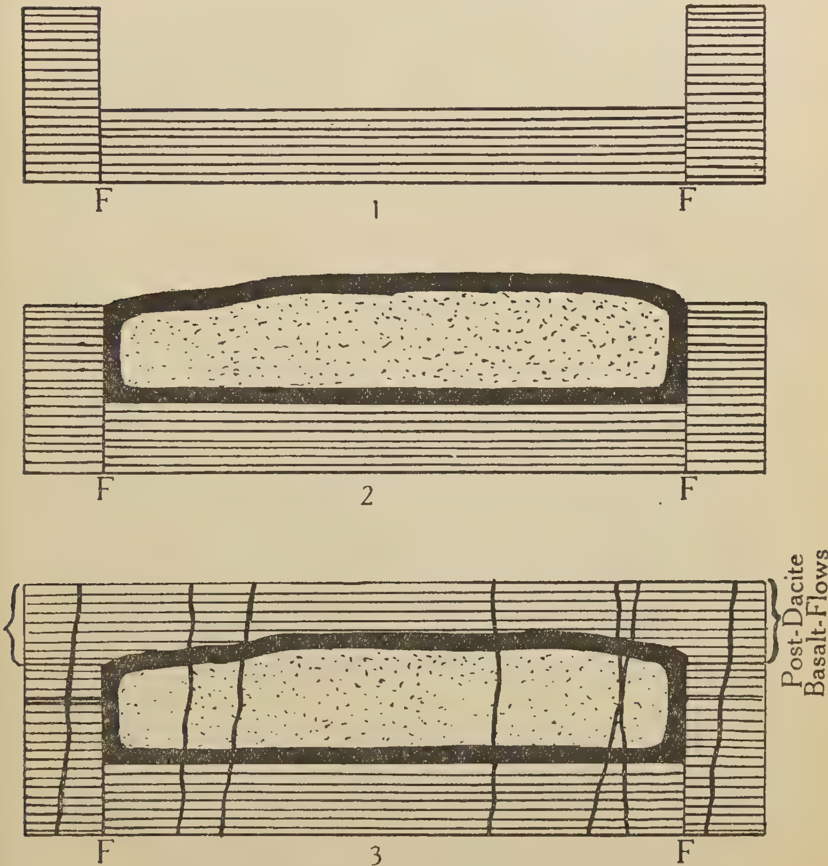
It is not a dyke. The presence of a base makes that clear, apart from the difficulty in accounting for its truncation above. If an intrusion, it must have resulted from a subterranean subsidence.

This explanation is difficult to accept for two reasons. First, the nature of the rock, with its thick and irregular glassy facies, and the contortion of the banding, is quite unlike that of other intrusive masses in Iceland—in which a glassy phase is usually absent, or but slightly developed, and banding, where present, much more regular. Secondly, the way in which the vesicular bases of the overlying basalts rest against the obsidian slope rules out the possibility of this being a fracture formed at the time of intrusion.

These two points are indicative of an extrusive origin for the dacite. The vertical section is that of an acid lava The upward succession of (1) brecciated obsidian, (2) banded pitchstone, (3) compact horizontally-bedded dacite, passing gradually into (4) dacite with contorted banding and capped by (5) obsidian, is characteristic of many undoubted flows in Eastern Iceland. The disposition of the banding is easily understood. At the bottom the lava flowed evenly under its own weight, but at the top viscosity had freer play. The section of the upper western part points to the submergence of the rhyolite by successive basalt-flows. The main difficulty in accepting the extrusive hypothesis is provided by the vertical sides. No lava 500 feet thick, and spreading out 1000 yards, will have vertical boundary-walls. The basalts abutting against the sides have clearly been cut off by fracture, as shown by the absence of vesicular structure or fineness of grain at the contact. No acid fragments occur between the basalts in the neighbourhood of the junction, and the lava did not spread out on a plain to be subsequently submerged by basalts.

The suggestion here advanced is that a subsidence took place in the basalt-plateau, and that an acid lava filled the depression. This dacite had a sloping upper surface, and successive basalt-flows first covered its western portion and finally the whole (fig. 5). The

Fig. 5.—*Diagrammatic sections illustrating the sequence of events.*



1 = Subsidence of a tract of basalts. 2 = Extrusion of dacite-lava: the black border represents the glassy and spherulitic facies. 3 = Submergence of the dacite beneath succeeding basalt-flows, and subsequent intrusion of dolerite-dykes.

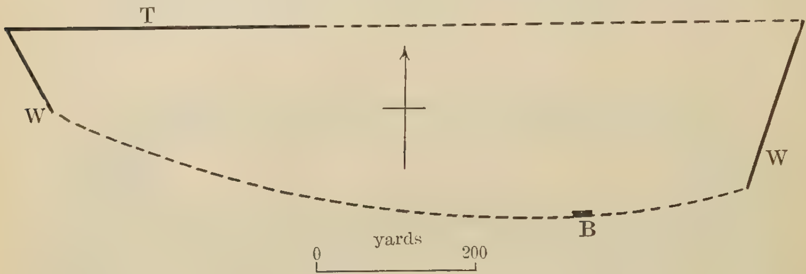
absence of an obsidian shell in the upper eastern part of the mass and the very weathered character of the dacite there may be due to contemporaneous erosion of what was the higher part of the flow.

In plan (fig. 6) it is seen that the eastern boundary is parallel to the line of fracture associated with the intrusions of Eastern Iceland; but the western boundary is not, and the depression may have been a cauldron-subsidence. The dacite cannot have extended far, as no trace of it is seen on the south side of Hamarfjord or in Bulandsdal to the north.

The explanation here given accounts for the intrusive and extrusive relations exhibited by one and the same rock-mass. It is remarkable that the lava should have filled the depression along the line of the cliff-face, and not overflowed on to the basalt plain.

The Rauthaskritha is another instance of an acid extrusion occurring in the midst of a suite of basic ones (19). Generalizations

Fig. 6.—*Plan of the Rauthaskritha.*



The continuous line marks the outcrop of the glassy facies at W, the vertical sides; B, the base; and T, the top of the dacite. The enclosed area is lithoidal dacite.

that the progressive differentiation of magmas will give rise to a rock series showing even gradations of composition have blinded some observers in Iceland to the facts, and many of the acid extrusives in the plateau-basalts have been regarded as intrusions. The coexistence of acid and basic rocks is the most striking feature of the Icelandic region, and led Bunsen to formulate the theory of two original magmas (1). In all phases of igneous activity—extrusive, plutonic, and hypabyssal, basic and acidic types occur together; and the prolonged coexistence in the Earth's crust, and absence of intermingling, of such extreme magmas is an important circumstance which must be taken into account when theories of petrogenesis are being formulated.

III. Petrological Description of Rock-Types.

Notes on the Rauthaskritha rocks have been given by Zirkel (3, p. 785), Schirlitz (4, p. 424), Helland (6), and Schmidt (7, p. 779). Some of the determinations which were made in the early days of microscopic work may now be corrected. The account of the occurrence of inclusions of quartz in the large felspars, to which some prominence has been given (13, p. 755), is erroneous.

Olivine was reported by Zirkel (3, p. 783). Schirlitz claimed this to be a mistaken determination of pyroxene (4, p. 426). Helland rediscovered the olivine; but it was again questioned by Schmidt, who regarded it as rhombic pyroxene.

The Rauthaskritha provides an interesting demonstration of the variety of rock-types that may result from different conditions of cooling of a homogeneous magma, without differentiation. All types contain phenocrysts of felspar, pyroxene, and olivine, with small magnetites and zircons. The ground-mass ranges from glass to holocrystalline. The specific gravity of the pitchstone from the western side of the flow (No. 83)[1] is 2·381, that of the central lithoidal mass (No. 116) is 2·622. Compared with the glassy rock this represents a reduction of 9·2 per cent. in specific volume. The contraction on crystallization accounts for the porosity of the stony dacite, and the cavities and open cracks in the spherulites.

In hand-specimen the contact-rock is often pale green, with a dull non-glassy lustre. In thin section circular and elongate areas of hyaline silica are seen in the glass, and these probably represent vesicular infillings. These areas commonly adjoin felspar-phenocrysts, the individuals and aggregates of which are fractured and dispersed. The specimen from the base of the eastern end of the flow (No. 110) is composed mainly of fragments of perlite, with some few inclusions of basic rocks. One large fragment of typical pumice is present.

The bulk of the contact-rock ranges from a lustrous black obsidian to a dull black pitchstone. In thin section these rocks exhibit perlitic and fluxion-structures. The glass is in some cases crowded with crystallites; in others there is a regular distribution of microlites—nearly all of felspar, with a few of pyroxene. The glass may be brown or colourless; the colour is usually developed more strongly adjoining the crystals, and especially bordering the spherulitic areas (No. 123).

The spherulites are seen to begin as scattered single globules (3 mm. across) in the black pitchstone (No. 123). They increase in number and size, and may form the whole of the rock, which is then a mass of closely fitting polygons due to mutual growth-interference (No. 122). Thin sections show that, although the spherulites may grow from phenocrysts as centres, they usually include them only by accident, and the felspar-microlites stream through with no change in orientation (Pl. XLII, fig. 2). In parallel light the spherulites can only be distinguished by their lighter colour and the presence of contraction-cavities and cracks which widen towards the centre.

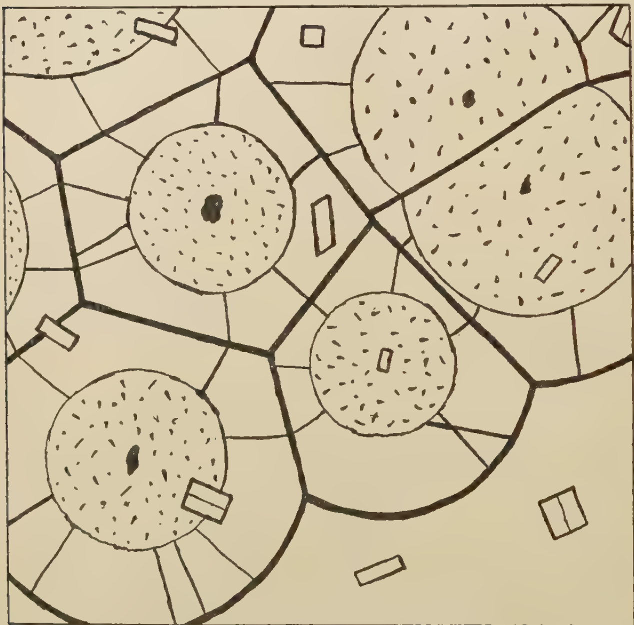
Between crossed nicols in some sections a feeble birefringence (·002 and less) reveals an irregular radial structure of positively elongated crystals. In many slices this arrangement is replaced by aggregates of poikilitic quartz-areas without radial structure.

[1] These refer to the numbers of the hand-specimens and thin sections in the Geological Department, Bedford College, London, N.W. 1.

This is due to recrystallization of the original spherulites, and in some cases the perlite interstitial to the rounded areas is also completely crystalline (No. 85).

One rock-type (No. 121) in hand-specimen is largely made up of spherulites 1 to 2 cm. across, comprising an outer white border to an inner spherical red area which forms about half the spherulite (fig. 7). Their outlines are commonly polygonal, due to mutual

Fig. 7.—*Spherulitic rock (No. 121).* × 3.



This illustrates the hollow centres, inner red spherical areas, outer polygonal form of spherulites where adjoining, circular boundaries to glass (bottom right-hand), felspar-phenocrysts, and radial cracks in the outer parts of the spherulites.

growth-interference, but are spherical to the glass. The radial cracks of adjoining spherulites are frequently continuous. In thin section the central area is seen to be composed of a confused aggregate of large poikilitic quartzes with felspar, and opaque inclusions probably representing altered pyroxene. The outer part contains smaller poikilitic quartzes, and the selenite-plate reveals traces of a positive radiate structure. Normal zoned spherulites due to a more thorough crystallization of the central portion are well known, and the spherulites here described were originally of that character. The subsequent recrystallization has also been more complete in the centre, probably due to the greater evolution of gases there (18, p. 273).

The ground-mass of the holocrystalline rock forming the bulk of the Rauthaskritha is composed of a felt of felspar and quartz-crystals, with magnetite and secondary iron-ore in small amount. A coating of hyaline silica has been deposited on the walls of the cavities.

The Phenocrysts.

The felspar shows multiple twinning after the albite and occasionally the pericline law. Zonal structure is prominent in most crystals. Extinction-angle measurements in negative bisectrix sections and those normal to (001) and (010) indicate an andesine with an anorthite percentage composition ranging from 50 per cent. in the centre to 30 per cent. in the periphery. The sanidine mentioned by previous workers was not found.

The pyroxene is euhedral, elongated along the vertical axis.

$$\gamma-\alpha=\cdot029\pm\cdot002.$$

The colour is grass-green. Pleochroism is shown only by basal sections in which:—

α' = light green,
γ' = brownish yellow.
Extinction $\gamma \wedge c=39°$ to $43°$.
Slight dispersion of axis 'A', $\rho>v$.

These properties indicate diopside. The phenocrysts form from 0·4 to 0·8 per cent. of the rock. The larger crystals are 0·7 mm. long, and inclusions of magnetite and zircon are frequent.

The olivine is commonly euhedral and equidimensional. Some crystals are elongated in the direction of the 'a' crystallographic axis, similar to some of the fayalites of Pantelleria (see 14, pl. ii, fig. 5). Occasionally irregular boundaries occur to felspar. Cleavage:—001, fairly good; 010, less perfect; 100 imperfect.

Pleochroism distinct in thin sections of normal thickness:— α colourless to faint yellow; β honey-yellow; γ faint yellow to honey-yellow.

Absorption $\beta>\gamma>\alpha$.
Birefringence (determined with a Berek compensator).
$\gamma-\alpha=0\cdot049\pm\cdot002$
$\gamma-\beta=0\cdot0093\pm\cdot0004$
Optical sign—negative
$2E=$ about $115°$.
Strong dispersion of the optic axes $\rho>v$.

These properties indicate an olivine closely approaching fayalite in composition. The maximum content of fayalite given by a pitchstone (No. 120) is 0·4 per cent. Inclusions of magnetite and zircon are common.

The fayalite has been preserved unaltered in the glassy rocks only, and not always in them. In the spherulitic and lithoidal types pseudomorphs are present, bearing testimony to the euhedral form of the original mineral. The pseudomorphs may be of serpentine, a mixture of iron-oxide and silica, hyaline silica only,

or iron-ore only. The solutions and gases liberated on the crystallization of the central mass of the dacite have attacked and often completely replaced the olivine and sometimes the pyroxene also. The fayalite is clearly an original early-formed phenocryst, and the flow-lines of the rock bend round it (Pl. XLII, fig. 1).

Minute magnetites and zircons are scattered throughout the rocks. The aggregation of the fayalite, diopside, and felspar-phenocrysts, and the concentration of the larger magnetites as inclusions in them, illustrate the tendency of the first-formed crystals to collect together in a magma, producing what Vogt has called 'synneusis' structure (20, p. 321). The order of crystallization was: (1) magnetite and zircon; (2) fayalite; (3) diopside; (4) andesine; and finally the magnetite, diopside (?), felspar, and quartz of the ground-mass. The pyroxene shows no tendency to form around the fayalite, which is devoid of any reaction-border.

The basic dykes are normal dolerites. One section (No. 109) shows a coarse-grained ophitic rock, with small olivine-phenocrysts and large, zoned, porphyritic plagioclase.

Analysis of Black Dacite-Pitchstone (No. 83) from the Western Junction, Rauthaskritha. By W. H. Herdsman.

SiO_2	71·47
Al_2O_3	12·69
Fe_2O_3	0·37
FeO	2·56
MgO	0·41
CaO	1·85
Na_2O	4·27
K_2O	1·59
H_2O+	4·25
H_2O-	0·39
TiO_2	trace
P_2O_5	0·09
MnO	nil
Total	99·94

Norm.

Quartz	34·02
Orthoclase	9·45
Albite	36·15
Anorthite	9·17
Corundum	0·61
Magnetite	0·70
Hypersthene	5·22

Position in the Quantitative Classification:—
1. (4) 3. 2. 4.

Specific gravity at 4° C. = 2·381
Refractive index of glass = 1·502

The analysis is that of a typical dacite, and occupies the same position in the Quantitative Classification as the obsidian from Hraftinnuhyrggur, Northern Iceland (18, p. 260). The magnesia has entered the pyroxene, and not the earlier-formed olivine. The basicity of the first-formed felspar is in accordance with the analysis, and, together with the zonal structure, is evidence of rapid growth. The large felspars are present in the same proportion in the rapidly chilled and slowly cooled rock, and with the other phenocrysts represent the excess over the eutectic, which consisted mainly of quartz, plagioclase, and potash-felspar, with small amounts of magnetite and pyroxene. The absence of quartz-phenocrysts is a striking anomaly.

IV. The Olivine-bearing Acid Rocks.

The occurrence of fayalite in cavities, veins, and as segregations in acid rocks is well known—and is generally explained as the result of crystallization of a physico-chemical system abnormally rich in water.

The presence of olivine as a normal phenocrystic constituent has not been so widely recognized, and the present enquiry is restricted to those acid rocks that contain considerable quantities of normative or modal quartz.

Zirkel first drew attention to the presence of olivine in trachytic pitchstones from Northern and Eastern Iceland (3, p. 783). Bäckström found olivine in the post-glacial 'liparite'-flow of Nâmshraun, South-Western Iceland (8, p. 644). Küch describes a dacite from Colombia with fresh olivines 2 mm. long (9, p. 185). Prior reported iron-olivine in obsidians from British East Africa, Ascension I., and Aden (10); and Weidman noted the widespread occurrence of fayalite in rocks from Wisconsin, including a hedenbergite-quartz-syenite and an amphibole-granite (11). Rosenbusch (13, p. 853) and Sœllner (14, p. 140) recognized fayalite in rocks from Pantelleria, and Washington has given analyses and descriptions of these (16). The only case described from the British Isles is that of the quartz-fayalite pitchstone from Arran, reported by Scott (15, p. 26). With the exception of the dacite from Colombia, the olivine is one approaching fayalite in composition.

Scott inclined to the view that the fayalite in the Arran rock was xenocrystic, and had crystallized from a basic magma, which had then been absorbed by an acid one (15, p. 27). The composition of this rock, regular distribution of the phenocrysts, and especially the fact that fayalite does not form in normal basic magmas, render this improbable. The regular distribution, euhedral form, and absence of reaction-borders show that the olivine in the Rauthaskritha rock was quite at home in the mother liquor. The iron-olivine phenocrysts in acid rocks are undoubtedly all normal crystallizations from the acid magma.

In the accompanying table are recorded the analyses of the olivine-bearing acid rocks, together with their normative quartz and modal minerals.

Many different rock-types are represented, and it is difficult to discover any common feature of composition which might be correlated with the presence of olivine. Excluding the Colombian dacite, which may be considered apart by reason of the magnesian character of its olivine, the low percentage of magnesia (a feature common to the majority of acid rocks) is notable, The non-occurrence of fayalite in basic rocks is due to their considerable magnesia content. Weidman, after noting the importance of the poorness in magnesia of the Wisconsin series, drew attention to the absence of ægirite in them, and suggested that the chemical conditions for the development of fayalite existed in magmas

Rock-Name.	*Obsidian*	*Pantelleritic Obsidian.*	*Comendite.*	*Hyalo-Pantellerite.*	*Quartz-Syenite.*	*Granite.*	*Trachyte.*	*Trachyte.*	*Dacite-Pitchstone.*	*Dacite.*
Locality.	Ascension.	B.E. Africa.	Pantelleria.	Pantelleria.	Wisconsin.	Wisconsin.	Pantelleria.	Pantelleria.	Hamarfjord, Iceland.	Colombia.
Reference[1]	159	337	335	327	287	941	157	281	—	387
SiO_2	72·71	64·00	72·21	69·33	61·18	67·99	65·27	63·30	71·47	63·36
Al_2O_3	12·80	10·43	9·72	8·62	19·72	15·85	13·50	16·38	12·69	16·35
Fe_2O_3	2·64	6·30	3·26	2·65	3·71	5·36	4·40	2·54	0·37	2·12
FeO	1·48	3·86	1·07	5·52	1·32	n. d.	2·52	2·36	2·56	3·05
MgO	0·10	0·34	0·29	0·52	trace	0·41	0·55	0·84	0·41	3·28
CaO	0·58	1·45	0·82	0·52	2·64	1·78	0·85	1·62	1·85	4·79
Na_2O	6·50	7·59	4·42	4·78	5·28	3·21	5·19	6·36	4·27	3·58
K_2O	3·87	4·59	4·98	4·71	5·66	4·81	4·21	4·41	1·59	2·92
H_2O+	0·48	0·17	1·96	2·35	0·32	0·30	1·98	0·83	4·25	0·99
H_2O-	—	—	0·24	0·27	—	—	0·14	0·10	0·39	—
TiO_2	—	0·78	0·62	0·85	—	—	1·09	0·71	trace	—
P_2O_5	—	—	0·10	—	—	—	0·17	0·30	0·09	0·13
MnO	—	0·37	0·05	0·27	—	—	0·27	—	—	—
Totals	101·16	99·88	99·74	100·39	99·83	99·71	100·14	99·75	99·94	100·57
Normative quartz.	21·54	10·44	31·14	28·02	3·00	—	17·10	5·58	34·02	15·36
Minerals associated with olivine (including magnetite).	Anorthoclase, Ægirine, Augite.	Anorthoclase, Ægirine.	Ægirine, Augite, Cossyrite.	Soda-microcline, Diopside, Ægirine-augite.	Hedenbergite, Quartz.	Quartz, Amphibole, Microperthite.	Soda-microcline, Augite.	Soda-microcline, Augite, Amphibole.	Andesine, Diopside.	Quartz, Augite, Hypersthene, Amphibole, Biotite.

[1] The reference is to pages in 'Chemical Analyses of Igneous Rocks' by H. S. Washington, Prof. Paper 99, U.S. Geol. Surv. 1917.

containing a large excess of ferrous oxide over ferric oxide (11, p. 556). As the table shows, however, ægirite and fayalite are not mutually exclusive, nor is a deficiency of oxygen visible in all the analyses. The fayalite is present in small amount, normally below 1 per cent., but as much as 5 per cent. in phases of the quartz-syenite (11, p. 554). It is usually euhedral when a phenocryst, but in glomeroporphyritic aggregates or in coarse-textured rocks it assumes shapes due to mutual growth-interference with other minerals, including quartz.

Clearly, like magnetite and the ferromagnesian silicates, fayalite is but slightly soluble in acid magmas, and is stable in presence of a considerable amount of free silica. The Rauthaskritha rock, with 34 per cent. of normative quartz, is the extreme type known in this connexion. That an orthosilicate may exist in equilibrium with a liquid containing more silica than that required to form the metasilicate is known to be possible, from the researches of Bowen and Anderson on the $MgO–SiO_2$ system. Forsterite may form in a melt containing 2 per cent. more silica than that required for the magnesium metasilicate (17, p. 500), and with quick cooling a mixture of forsterite, clino-enstatite, and cristobalite has been obtained.

Washington claims that this affords an explanation of the occurrence of fayalite in highly silicic rhyolite and pantellerite (21, p. 469); but the high content of free silica of these rocks is of a very different order from that of 2 per cent. The system $FeO–SiO_2$ has not yet been worked out. If it is similar to the $MgO–SiO_2$ system, one might expect the invariant point fayalite-metasilicate-liquid to show a considerable excess of silica.

Indications are not wanting that the iron system may be of a character different from the magnesian one. Reaction-rims, which are so common a feature around magnesian olivines, and for which the experimental work has so satisfactorily accounted, are not shown by the fayalite, even in slowly cooled quartz-syenite. Minerals approaching iron metasilicate in composition are unknown in igneous rocks. Gorgeu, who prepared fayalite by heating ferrous chloride and silica in a stream of moist hydrogen, found that, contrary to his experience with the manganese salt, he was unable to produce the metasilicate on increasing the proportion of silica (5). It seems probable that the metasilicate will not appear in the $FeO–SiO_2$ system, and that the fayalite will form a eutectic with silica. It will then take its place in the group of minerals which Vogt has demonstrated to be but slightly soluble in acid magmas on the theory of the existence of ternary eutectics (20, p. 518); and its presence in acid rocks would be satisfactorily explained.

The olivine reported in the dacite from Colombia is described as a normal basaltic one (9, p. 185). In his account of the lavas Küch observes that the olivine and the rhombic pyroxene were to a great extent mutually exclusive. This occurrence would indicate that magnesian olivines are also capable of existing in presence of

much free silica, and we might explain their rarity in acid rocks as being due to the common low magnesia-content of these. Further information regarding the composition of this olivine is needed.

The differences which, it is suggested, exist in the behaviour of the iron and magnesium or of the silicates, indicate the possibility that a continuous series of solid solutions does not exist between forsterite and fayalite. Olivines of a composition between that of fayalite (FeO, 61 per cent.) and hyalosiderite (FeO, 30 per cent.) are very rare, and have not been produced artificially. It is significant that the general law establishing the similarity of the FeO–MgO ratio in ferromagnesian silicates to that obtaining in the magmas in which they have grown (20, p. 537) is broken in the fayalite-bearing rocks, in which magnesia is practically absent from the early-formed olivine. This is all the more noteworthy as the magnesium silicate is normally concentrated in the first-formed olivines of basic rocks.

The recognition of fayalite as a normal phenocryst in acid rocks, renders its occurrence in lithophysæ more explicable. Fayalite has been described in the lithophysæ of an obsidian from Hrafntinnuhryggur, Northern Iceland (18) and the obsidian is very similar in composition to that from the Rauthaskritha. The chemical composition of lithophysic mineral aggregates is the same as that of the parent rock, and they may be regarded as a product of normal devitrification. Under conditions of less rapid chilling, phenocrysts of fayalite would probably have appeared in the Hrafntinnuhryggur obsidian. The formation of the fayalite is not essentially due to the differences in the physico-chemical conditions prevailing on the cooling of the magma and those existing at a much lower temperature (see 18, p. 265).

I am indebted to Miss E. M. Guppy, B.Sc., F.G.S., for the specific gravity determinations.

V. Summary and Conclusions.

The acid rock-mass is exposed in cliffs of Tertiary plateau-basalt. It is 500 feet thick, and extends for 1000 yards. The lithoidal dacite shows prominent flow-banding contorted in the upper part, and is encased in a shell of glass. At each end of the section basalts abut against vertical walls of chilled dacite. The intrusive and extrusive relations exhibited by the mass, are explained on the hypothesis that the dacite was not an intrusion as hitherto maintained, but a lava-flow which filled a depression in the basaltic plateau, and was subsequently submerged beneath succeeding flows of basalt.

Attention is drawn to the evidence indicating the co-existence of extreme acid and basic magmas throughout the Tertiary cycle of igneous activity in Iceland.

Phenocrysts of fayalite are distributed throughout the flow. They were one of the first minerals to form from the magma, which contained more than 30 per cent. of normative quartz.

A review of the acid rocks bearing normal phenocrystic olivine is given. They include representatives of many rock-types. With one exception, the olivine is rich in iron. It is concluded that, in the early stages of cooling, the iron orthosilicate is in equilibrium with magmas containing a considerable amount of free silica.

Evidence is cited in support of the view that the behaviour of fayalite to silica is different from that of forsterite, and it is suggested that a eutectic exists between fayalite and silica.

My attention has been drawn to the following two papers by J. H. Whiteley & A. F. Hallimond in the Journal of the Iron & Steel Institute for 1919:—'The Acid Hearth & Slag' vol. xcix, p. 199, and 'The Action of Iron Oxides upon the Acid Furnace-Structure' vol. c, p. 159. The authors have obtained evidence of the existence of a binary eutectic fayalite-silica in the proportion of 6 : 1, and also of a ternary eutectic fayalite-magnetite-silica. The diagram given of the system FeO–MnO–SiO_2 shows the existence of the metasilicate of manganese, but not that of iron, which is in accord with Gorgeu's work (*op. supra cit.*). The suggestions made above are thus supported. The proportion of silica in the fayalite-silica eutectic is not, however, high, and we must look to the other constituents of natural slags and perhaps different cooling conditions as factors responsible for emphasizing the stability of fayalite in presence of silica.

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EXPLANATION OF PLATES XLI & XLII.

PLATE XLI.

Fig. 1. The western end of the Rauthaskritha. The abrupt truncation of the basalts by the rhyolite is seen. The gully marks the site of the actual contact, and on its eastern side is the wall of obsidian and spherulitic rock. The belt of rock seen *in situ* beneath the overlying basalts is obsidian. Other exposures and the scree-material are composed of lithoidal rhyolite.

2. This photograph is illustrated in the western half of text-fig. 4, p. 553. The gully on the left marks the site of the dyke (5 in fig. 4). The horizon of separation of the two basalts overlying the obsidian can be clearly seen on the right.

PLATE XLII.

[All in ordinary light.]

Fig. 1. Serpentine pseudomorph of olivine in pale-brown glass. Flow-structure of ground-mass brought out by lines of crystallites (No. 10). × 30.

2. Spherulite in glass. The felspar-microlites are arranged independently of the radial growth. The central cavity is seen, and a phenocryst of diopside outside the spherulite (No. 123). × 8½.

3. Fayalite (010) in the centre (with many magnetite inclusions), felspar, and magnetite. Fluxional disposition of the felspar-microlites in the glassy ground-mass (No. 120). × 34.

4. Aggregate of felspar, fayalite, diopside, and magnetite. The dark elongated area on the upper left-hand of the aggregate represents pyroxene surrounding olivine. Glassy ground-mass, with crystallites and microlites (No. 117). × 38.

5. Hyalite-pseudomorphs of olivine, with felspar. Spherulitic ground-mass (No. 124). × 25.

6. Olivine-pseudomorph in hyalite and iron oxide. Micropoikilitic ground-mass (No. 85). × 85.

DISCUSSION.

Dr. H. H. THOMAS stated that he had been much interested in the paper, and thought that the Author had put forward the most probable explanation of a remarkable field-occurrence. In confirmation of the Author's view that iron-olivine and silica may co-exist in a state of equilibrium, the speaker called attention to papers by Mr. J. H. Whiteley & Mr. A. F. Hallimond recently published by the Iron & Steel Institute. It was there proved that a binary eutectic of iron-olivine and silica was a normal product of the acid-hearth steel-furnace. The ternary eutectic fayalite-magnetite-silica had also been described and figured.

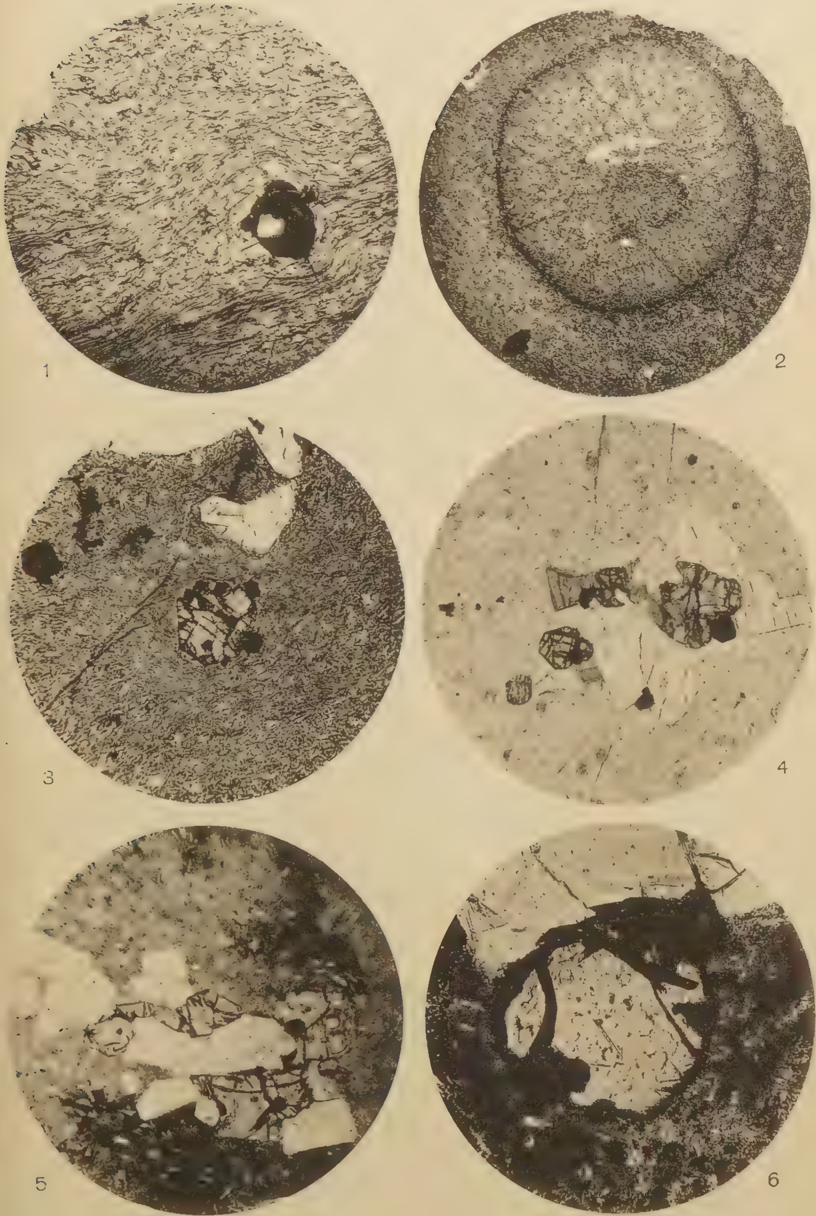
Dr. G. T. PRIOR referred to some recent experimental work suggesting that the presence of olivine in a highly siliceous rock might be due to rapid cooling.

Fig. 1.—The Western End of the Rauthaskritha.

L. H. photo.

Fig. 2.—Basalts and Dacite, Eastern End of the Upper Obsidian Exposure.

L. H. photo.



L.H. photomicro

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IGNEOUS ROCKS FROM HAMARFJORD.

Sir Thomas Holland referred to the numerous instances now known of the clean separation of acid and basic fractions, without intermediate products, in dykes, where the two fractions consolidated together, and in larger masses where, by the breakdown of the early-formed basic framework, separate masses of granophyre and gabbro were formed. The old assumption of a gradual transition in consolidation-products had been the cause of the surprise expressed at the discovery of fayalite in rhyolitic lavas; but its occurrence involved no greater chemical difficulty than the early separation of magnetite in acid rocks. He regarded this paper as an important contribution to the theoretical questions involved, and accepted the Author's explanation of the occurrence of a rhyolitic mass in a predominantly basaltic series of flows, as somewhat similar to that described by Dr. L. L. Fermor as associated in Kathiawar with the Deccan basaltic flows.

The President (Dr. J. W. Evans) welcomed the evidence adduced by the Author in favour of the discontinuous differentiation of igneous magmas. The speaker had long contended that such a differentiation occurred into an acid magma rich in volatile constituents and in a basic magma with a similar proportion of such constituents. Dr. W. A. Richardson had recently shown that the statistics of the frequency of the occurrence of igneous rocks of different chemical composition indicated a primary discontinuous differentiation into acid and basic magmas, followed by a continuous differentiation, either magmatic or due to crystallization.

The crystallization of ferriferous olivine or fayalite from an acid magma appeared to be related to the fact that a hypersthene in which the magnesia was entirely replaced by ferrous iron did not exist, at any rate as a product of magmatic crystallization.

Dr. L. J. Spencer drew attention to the occurrence of fayalite in the Mourne Mountains granite.

The Author, in reply to Dr. Prior, said that it did not appear that rapid cooling was necessary for the production of an olivine-bearing acid rock, as fayalite had been found in amphibole-granite. In the Rauthaskritha the iron-olivine was unaltered in the glassy rocks only, but euhedral pseudomorphed areas of the lithoidal rhyolite showed that the mineral had existed there also.

The President had drawn attention to the fact that a pyroxene approximating in composition to iron metasilicate was not known, and, in this connexion, the absence of reaction-borders to the fayalite was significant. As Sir Thomas Holland had said, the occurrence of olivine was analogous to that of magnetite in similar rocks, and this was supported by the existence of a fayalite-magnetite-silica eutectic prepared by J. H. Whiteley & A. F. Hallimond, to which Dr. Thomas had drawn attention.

For full light on the problem we must await the systematic experimental investigation of the FeO-SiO_2 system. It was regrettable that there was no prospect of such work being carried out in this country.

The fayalite of the Mourne Mountains was found in pegmatite, and such occurrences were not discussed by the Author.

23. *The* Upper Towy Drainage-System.

By Owen Thomas Jones, M.A., D.Sc., F.G.S., Professor of Geology in the Victoria University of Manchester. (Read February 6th, 1924.)

[Plates XLIII–XLV.]

Contents.

I. Introduction.

The most remarkable feature in the physical geography of Wales is undoubtedly the great plateau which extends almost without interruption from near the coast of Denbighshire in North Wales through Central and South Wales, where it occupies a large area of the counties of Cardigan, Carmarthen, Radnor, and probably also of Brecon. It truncates alike the highly folded Lower Palæozoic rocks of North and Central Wales and the gently inclined Old Red Sandstone marls of Breconshire. Its surface is apparently little influenced, either by the attitude of the rocks or by their lithological characters.

It abuts against the mountains of North Wales between Cader Idris and Snowdonia, which in places rise abruptly above its level,[1] while southwards it extends to the foot of the great Upper Old Red Sandstone escarpment of Breconshire and Carmarthenshire, which overlooks it as a line of high cliffs overlooks a level foreshore.

Sir Andrew Ramsay[2] attributed the formation of the plateau to marine denudation, and at one time regarded[3] the escarpment of the Brecon Beacons as an ancient line of cliff.

Occasional references to the plateau occur in later publications. I have given reasons[4] for distinguishing in Central Wales two distinct plateaux: namely, the Higher Plateau described above, and the Coastal Plateau which lies south of the Dovey Estuary,

[1] W. G. Fearnsides, 'Geology in the Field' Geol. Assoc. Jubilee vol. (1910) p. 820.

[2] Mem. Geol. Surv. vol. iii (1866) pp. 236–38; 2nd. ed. (1881) pp. 328, 329.

[3] *Ibid.* vol. i (1864) 'The Denudation of Wales' pp. 331 & 333.

[4] 'Aberystwyth & District: a Guide prepared for the Conference of the National Union of Teachers at Aberystwyth' 1911.

and, extending inland from the coast of Cardigan Bay for a distance of 3 to 15 miles, is sharply marked off from the High Plateau on the east.

The Coastal Plateau was attributed to marine erosion. It is a striking feature of the country between Aberystwyth and Cardigan,

'where looking north or south across the transverse valleys, the landscape frequently appears as a great and gently inclined plain with a seaward slope and bounded by distant inland hills, easily comparable to an existing line of lofty coast.' (A. C. Ramsay, *op. supra cit.* p. 327.)

Ramsay ascribes the formation of such a plateau to marine denudation, and accounts for its slight seaward slope by an exceedingly slow depression of the land during the progress of marine erosion.

This region, in which the relation of the background of high hills inland to the plateau inevitably suggests comparison with that of the line of present cliffs to the tract of Cardigan Bay, has some claim to be regarded as the type area of Ramsay's plain of marine denudation.

A general account of these plateaux was given by Dr. L. Sawicki,[1] who was a member of a party conducted through Central Wales by Prof. W. M. Davis in 1911. I had the privilege of acting as a guide to the party while in the neighbourhood of Aberystwyth, and of discussing the origin of the plateau with Prof. Davis. Dr. Sawicki attributes the plateau (or plateaux) to subaërial denudation, although Prof. Davis appears to have been convinced that there was in this particular region some justification for Ramsay's view.[2]

The plateau features of this and other British areas are discussed at some length by Mr. C. B. Travis,[3] and are regarded as peneplains formed as the result of subaërial agencies.

After this brief reference to the two opposing opinions on the origin of these features, I do not propose in this communication to consider them further; but rather to indicate certain lines of investigation which may help to solve the problem of their origin.

In Central Wales the High Plateau has been deeply dissected by numerous rivers, some of which, such as the Severn, the Wye, and their tributaries, flow eastwards, ultimately reaching the Bristol Channel; others, such as the Rheidol and the Ystwyth, flow westwards across the Coastal Plateau into Cardigan Bay. The Teifi, which reaches that bay much farther south, lies mainly on the lower Plateau, its course being for some distance almost parallel to the boundary between the Coastal and the High Plateau. The Towy with its main tributaries arises near the summit of the High Plateau, and discharges into Carmarthen Bay.

[1] 'Die Einebnungsflächen in Wales & Devon' Sitz. Ber. Warschauer Gesellsch. Wissensch. 1912, pt. 2.

[2] Annales de Géographie, vol. xxi (1912) p. 7.

[3] Pres. Add. Liverpool Geol. Soc. vol. xii (1914) pp. 1–31.

Although the Coastal Plateau has not hitherto been differentiated from the High Plateau in the south of Carmarthenshire, it is probably represented there.

The area of the Towy drainage-system was selected, in preference to several other drainage-systems which had been cursorily examined, in the hope that it will furnish a clue to the relation of this and adjoining river-valleys to the surrounding plateaux.

The Towy and its chief tributaries rise near the borders of Cardiganshire, Breconshire, and Carmarthenshire. The main river flows southwards, receiving in succession the Camddwr and Doethie-Pysgotwr,[1] which come in from the north-west. South-west of the Pysgotwr the Cothi flows for a few miles towards the Towy, and then turns abruptly at right angles to enter the river at Nantgaredig many miles below. There is clear evidence that the portion which may be distinguished as the Upper Cothi formerly continued south-eastwards along the Gwenffrwd Valley into the Towy, and has been diverted into its present course by capture (see p. 583). The Camddwr and Doethie-Pysgotwr[1] join the main river above Rhandirmwyn, which is a mining village 7 miles north of Llandovery and about 15 miles from the source of the Towy. In the 25 miles which intervene between this place and Carmarthen, where it becomes tidal, the Towy receives only four tributaries comparable in size with those mentioned above: namely, the Brân at Llandovery, the Sawdde at Llangadock, the Cothi at Nantgaredig, and the Gwili at Abergwili.

Above Rhandirmwyn there is a remarkable contrast between the upper and the lower portion of each of the valleys, and, if the longitudinal profiles are plotted from the data on the 1-inch Ordnance Survey map, a marked discontinuity of gradient in the middle portion of each valley becomes evident, and the contrast between the immature or youthful character of the lower reaches of the valleys and the mature forms of their upper reaches is clearly seen on the profiles. As the tributaries of the Towy below Rhandirmwyn do not apparently reveal these features, the explanation thereof must be sought for above that place.

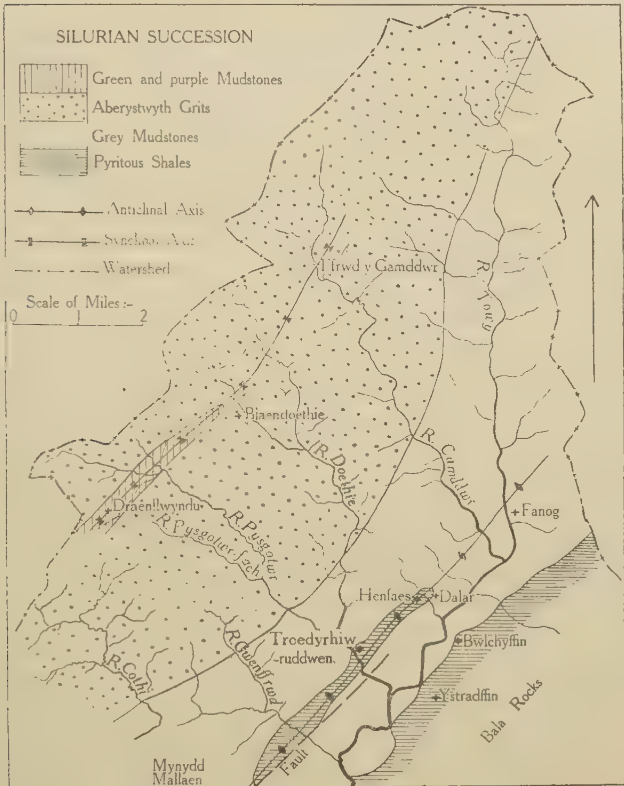
Preliminary observations were made many years ago, from which it appeared that the longitudinal profiles of the valley-floors in the upper reaches were smooth curves which could be expressed by a simple mathematical formula; but, as most of these floors lay above the 1000-foot contour-line, where contours are only shown at 250-foot intervals, while spot heights near the streams are exceedingly rare, there was a considerable element of uncertainty in drawing the profiles. Their apparent smoothness might, therefore, be a deceptive result of insufficient data. The further pursuit of the enquiry was long delayed, pending an opportunity of examining the valleys in detail.

During the summer of 1920 a large number of levels at various points of the valleys were determined by means of a theodolite, in

[1] See footnote, p. 581.

order to obtain the materials for drawing the profiles more accurately than had been possible previously. Still more recently (March 1921) the valleys were levelled by Mr. Harold Hopkins and myself. The present communication embodies the results of these determinations and of observations made concurrently on the form and structure of valleys.

Fig. 1.—*Geological sketch-map of the Towy Basin above Rhandirmwyn.*



II. The Geology of the Area.

Although the purpose of this investigation was the study of the drainage-system, some observations were made on the geological succession and on the salient structural features of the area, in so far as they appear to influence the physical features (see fig. 1). The rocks belong almost exclusively to the Valentian Series. The boundary between them and the Ordovician ranges north-eastwards between Rhandirmwyn and Abergwesyn (in the Irfon valley) along

the ridge which divides the drainage of the Towy from that of its tributary, the Brân, on the east. The eastern side of the ridge is composed of dark-grey shales, mudstones, and grits of Bala age, which extend for about 4 miles across the strike to the Sugarloaf, on the main road from Llandovery to Llanwrtyd Wells. This conspicuous conical hill is formed of dark graptolitic shales, comparable with the *Dicranograptus* Shales of other Welsh areas. The lead- and zinc-lodes of Rhandirmwyn lie mainly in grits with associated shales, which apparently occupy high horizons in the Bala formation.

The lower beds of the Valentian are dark-grey, striped, pyritous shales, weathering to a deep rusty colour or in other cases bleached ashy-white. They dip north-westwards at angles of 30° to 40°. Their junction with the underlying Bala formation has not been traced, but a considerable thickness of rocks presenting the same characteristics is exposed in the neighbourhood of the Towy valley, as, for instance, around Ystradffin and Bwlchyffin. West of the main outcrop they reappear along the core of an anticline which crosses the Gwenffrwd and Doethie valleys about a mile above the confluence of these rivers with the Towy.

This group is overlain by a great thickness of greenish-grey, striped, flaggy mudstones with subordinate beds of calcareous sandstone, containing in places abundance of shelly fossils, among which brachiopods, gastropods, and infrequent trilobite-fragments can be identified. The fossils are, however, so small and so poorly preserved that even a generic determination is only possible occasionally. These strata also dip generally north-westwards, and with a few minor undulations extend for about 2½ miles in that direction. The upper beds appear to be softer and less resistant than the lower, and this difference is reflected to some extent in the forms of the valleys of the Towy and those of its tributaries which traverse the outcrop of this group.

The mudstones are followed by a grit group, composed of rapidly alternating beds of thin evenly-bedded grits and dark shales. The grits are distinguished by numerous worm-trails and other markings on their under surfaces. This group also is of considerable thickness, and extends with a north-westward dip for over 3 miles across the strike. Near Bonborfa, in the upper part of the Pysgotwr valley, it is overlain by soft pale-greenish mudstones which, at a place known as Draenllwynddu, contain a deep maroon-coloured band.

The general succession herein described was briefly recorded in a former paper in this Journal.[1] The rusty pyritous shales may be correlated with the Eisteddfa and Rheidol Groups of the Pont-Erwyd district, but it is evident that their thickness has greatly increased. They may also be compared with the Gwastaden rocks of Rhayader, which occur along the same strike on the north-east, or with similar shales mapped by Miss I. L. Slater & Miss H.

[1] Q. J. G. S. vol. lxviii (1912) p. 328.

Drew in the Llansawel district, about 10 miles away to the south-west and also on the same line of strike. The age of the overlying mudstone group has not been fully investigated, but in the left bank of the Pysgotwr, south of Troedyrhiw-ruddwen, the basal beds exhibit the characteristics of the *Mesograptus-magnus* Zone, to which they may probably be attributed. This is confirmed by the discovery of *Monograptus communis* in the immediately underlying rusty shales. The mudstone group may, therefore, be regarded as approximately equivalent to the Castell Group, together with the lower part of the Ystwyth Stage of North Cardiganshire, or the Gigrin Mudstones and the Pale Slates of Rhayader. The overlying grit group is the south-western continuation of the Cwmystwyth Grits; but the proportion of grit to shale is less than around that place, and it is probable that the grit conditions began somewhat earlier than in the northern district.

The lithological characters of the pale-green and maroon-coloured mudstones, which are the youngest rocks in the district, recall the Dolgau Mudstones or highest Valentian rocks described by Dame Ethel Shakespear in the Tarannon area [1]; but, in the absence of fossils, it is not possible to prove the time-equivalence of the two groups.

The outcrop of the pyritous shales is indicated by a strike-hollow, which extends north-eastwards for over 7 miles from Ystradffin to Abergwesyn, and probably beyond that place. The overlying rocks, being more resistant, give rise to a well-defined eastward-facing scarp which is a dominant feature of the scenery around Ystradffin.

The general course of the Towy for nearly 5 miles is almost parallel to the outcrop of the shales, and only a few hundred yards distant therefrom. The river swings repeatedly towards the outcrop, and in one place actually reaches it; but, in each case, it turns away across the harder beds. The valley of Nantffin which follows the strike of the shales is astonishingly wide for so small a stream.

The anticline along which the rusty shales are rolled up west of their main outcrop is an important feature in the district. It can be traced from the edge of Mynydd Mallaen across the Gwenffrwd and Doethie valleys, as far as Henfaes and Dalar near Nant Brianne. The greenish-grey flaggy mudstones which overlie the shales form a prominent scarp on each side of the anticline in the Gwenffrwd valley, and again near Troedyrhiw-ruddwen in the Doethie valley. The anticlinal axis is probably situated midway along the shale-outcrop. From Dalar the anticline can be traced as far as the Camddwr valley, which it crosses about half a mile above its confluence with the Towy, and the same structure will probably account for the eastward dips on the slope above Fanog. It apparently strikes towards the conspicuous hill of Drygarn Fawr (2115 feet), 4 miles north of Abergwesyn, which is composed of

[1] Q. J. G. S. vol. lxii (1906) p. 644.

massive grey grits lying either at the base of the Silurian (Gwastaden Grits of Rhayader), or in the Bala formation. The strike of the fold is thus almost parallel with the base of the grey mudstone group and with the average course of the Towy valley for about 5 miles above Rhandirmwyn.

The pale-green and maroon-coloured mudstones which are exposed at Draenllwynddu extend north-eastwards from that place for nearly $2\frac{1}{2}$ miles, and occupy a narrow strip of moorland on each side of the Pysgotwr valley. This is the youngest group of rocks exposed in Cardiganshire, and its outcrop being less than half a mile wide defines closely the axis of the fold which I have elsewhere named 'The Central Wales Syncline.' Farther north-east in the Doethie valley the same structure traverses lower beds near Blaen Doethie, and can be recognized again near Ffrwd y Gamddwr in the Camddwr valley. At this locality the centre of the syncline is occupied by massive grits which lie considerably below the base of the pale mudstone group, whence it may be inferred that the syncline pitches southwards at a small angle. Its axis strikes north-eastwards towards the col between the Ystwth and Elan valleys, where similar pale mudstones occupy a narrow syncline overlying the grit group of Cwmystwyth.

The Glacial Deposits.

In the upper parts of all the valleys considerable deposits of Boulder Clay occur, in which the streams have developed alluvial flats of varying width. The glacial deposit has a relatively level surface, and stands like a terrace on each side of the river-channel; in the other direction it abuts sharply against the slopes and spurs of the valley which are submerged beneath it. Owing to the concealment of their lower portions, the slopes on opposite sides of the valley are separated by a considerable width of nearly level floor, which gives an open aspect to the valley as a whole. The Boulder Clay is of local origin, consisting of boulders of the local rocks in a blue plastic-clay matrix.

Big boulders of a coarse conglomerate which has not been found *in situ* occur in some parts of the Towy and Camddwr valleys; one such lies by the side of the river and road half a mile below Moel Prysgau, while similar boulders are fairly common on the floor of the valley about Nant Stalwyn and between that place and Abergwesyn. Near Nant Stalwyn the rocks are strongly glaciated, the striæ indicating a movement of the ice from west to east across the valley, and there is evidence of movement in the same direction near Llanerchyrfa in the Irfon valley, 2 miles distant on the east. As these points lie 200 to 300 feet above river-level, the striæ probably denote the general trend of ice-movement in the district, but the form of the Towy valley suggests that there was some ice-movement in the direction of the valley. On the road a quarter of a mile north of Trawsnant, some miles below Nant Stalwyn, and on the path about half a mile north-west of Bwlchyffin, the

striæ are in each case parallel to the valley, and the ice-movement appears to have accommodated itself to the varying trend of the valley-slopes. The glacial deposits diminish in amount downstream, and in most of the valleys there are tracts some miles below their source which are almost free from drift. Not far above Rhandirmwyn where the Towy valley widens, its floor is covered to a considerable depth with superficial deposits. Some Boulder Clay usually adjoins the slopes; but, towards the centre of the valley, it has undergone erosion and redistribution so as to form extensive gravel-terraces, some of which stand high above the level of the river. The erosion of these has in turn furnished the materials of the recent alluvium.

A brief description of the Towy valley and its tributaries above Rhandirmwyn will indicate the nature of the problems which they present. For convenience of reference the centre-line of the floor of each valley was laid down on 6-inch maps, and the distance measured along it in miles and tenth miles from some convenient point near the source of the stream. The mile-points are shown in Pl. XLIII, and reference will be made to them in describing localities in the valley.

III. The Towy Valley.

The Towy rises about 7 miles east of Tregaron on a moorland plateau, from which also spring the head-waters of the Teifi on the west and the Irfon, together with some tributaries of the Claerwen which flow eastwards into the Wye. In this locality the plateau reaches its highest point on Bryngarw (1872 feet) near the source of the Irfon; but its average height is somewhat below 1700 feet. The river indicated on the Ordnance Survey map as the Towy flows due south from its source at about 1500 feet towards Moel Prysgau, and is there joined from the west by Nant Gwinau, which rises at an altitude of about 1600 feet near Penybwlch, between Moel Prysgau and Pont Rhydfendigaid in the Teifi valley. For the reasons that Nant Gwinau is somewhat longer than the stream called Towy, and also has a smaller gradient which connotes a larger volume, I regard it as the main headwater and the stream flowing into it from the north as a tributary. Distances along the Towy valley are, therefore, measured from near Penybwlch.

The slopes of the Nant Gwinau valley are smooth and gently convex, and, as their lower portions are buried beneath glacial deposits, those on opposite sides are set at a considerable distance apart. Their profile, taken in conjunction with the width of the Boulder-Clay tract that covers the floor, gives to the valley a thoroughly mature aspect, which becomes more strongly marked as the source of the stream is approached. In that direction the slopes and spurs of the valley gradually tone down, and ultimately merge into slight inequalities on the surface of the plateau. It may be noted that the upper ends of most of these valleys fade away in a similar manner, and funnel-shaped valley-heads are

exceptional. This relation of the valley-slopes to the plateau is evidently a systematic feature.

The description of the Nant Gwinau valley applies in essential particulars to that which joins it at Moel Prysgau. In each the tributaries are at grade with the main river; but, despite this and the mature appearance of the valley-slopes, it is evident that the river is not in perfect adjustment with its channel, for, in flowing across the strike of the strata where grits alternate with shales, cascades of a few feet and occasionally reaching 10 to 15 feet occur.

From Moel Prysgau (2·2) the valley runs almost due south to the junction of the Camddwr (9·6), three-quarters of a mile below Fanog. The floor of the valley gradually descends from about 300 to over 600 feet below the level of the plateau, and as the increase of depth is not accompanied by a corresponding increase in width, as measured by the distance between the brows of the valley, the slopes become gradually steeper. Owing to the smaller width of the floor the spurs on opposite sides of the valley are somewhat closely set, and in a view up or down between Nant Stalwyn (4·6) and Pantyclwydau (7·5) they overlap considerably. The form of the slopes is but slightly obscured by Boulder Clay, the amount of which is insignificant as compared with that in the neighbourhood of Moel Prysgau. Certain other differences are apparent in the transverse profile of the valley; the smooth convex form is confined to the brow of the valley on each side, and lower down the slope it gives way to a more rugged and irregular profile, or to a concave curve. Occasionally, the smooth curve in the upper part of the slope ends abruptly in a scarp with scree at its foot. The cross-section, especially of the lower flanks of the valleys tends, therefore, to assume a distinct U-form (see fig. 2). For about 3 miles below Moel Prysgau the river-channel is excavated mainly in rock which strikes obliquely across it, and partly in Boulder Clay below which the river frequently encounters rock, and it is evident that its bed coincides approximately with the solid floor of the valley. Half a mile above Nant Stalwyn (4·6) and again below Cwmdu (6·2) a narrow gorge 10 to 12 feet deep has been cut through what appears to be a rock-barrier extending across the valley. There is evidence in some cases that, where the river cuts through rock, there is another channel alongside which is concealed beneath drift; but in other cases this is improbable, and the discontinuities of gradient seem to reveal real (although slight) inequalities in the rock-floor of the valley. The lower ends of the tributaries for a distance of 200 to 300 yards, corresponding to a vertical descent of perhaps 60 to 70 feet or more, cascade over rock before entering the river; but higher up these streams have a continuous gradient which, together with the smooth convex outline of their slopes, indicates a mature condition and complete adjustment between the tributaries and their own valleys. These features are shown by Nant yr Ergyd and Nant y Bont (3·5), Nant Tadarn (4·1), Hirnant (4·3), and Nant y Gerwyn (5·0) and may be seen also for about 2 miles below Nant Stalwyn—as, for instance, in Nant Cwmdu

Fig. 2.—*Upper part of the Towy Valley, showing mature features.*

Fig. 3.—*The Towy Valley above Fanog: rejuvenation beginning.*

(6·0) and Nant y Fleiddiast (6·6). At the ford (7·8) south of Pantyclwydau, the Towy lies in a short rock-gorge which has been excavated to a depth of 10 to 15 feet below a wide flat-floored valley. The tributary Nant yr Ych, which enters at that point, appears to have been graded with that floor. The difference of level between the lower end of the tributaries and the main river in this locality is, however, trifling.

Below Ty'n Graig (8·1) a significant change in the character of the valley sets in; the river (see fig. 3, p. 577) enters a rocky channel which rapidly develops into a deep narrow chasm, and descends through a vertical distance of about 130 feet in three-quarters of a mile. The chasm has been excavated in the floor of a pre-existing valley, both slopes of which are almost wholly preserved. Below the point (9·0) south of Fanog, where the river emerges from the gorge, the floor of the present valley is still narrow and rocky; but nearly all traces of the pre-existing floor have there been obliterated. It is possible that certain narrow ledges which occur on each side are remnants of it; but, as such ledges occur at various heights, and may in some cases be due to glacial erosion, they do not afford a reliable means of estimating its former level. One of these ledges, at a level of about 820 feet O.D. and terminating in a steep bluff overlooking the river, is crossed by the road half a mile south of Fanog; while another, a few yards away to the south, is about 15 feet lower. There is thus a marked difference in their levels within a short distance. The widest and most conspicuous ledge forms a gently sloping platform west of the Towy at its junction with the Camddwr. Its lower margin coincides with the 800-foot contour-line, and terminates in a steep bluff; its upper edge is about 30 feet higher. A small platform at a somewhat lower level occurs about 300 yards away to the north on the same side of the valley. The platform near the mouth of the Camddwr is certainly a remnant of the old valley, the rock-floor of which at this point is thus in the neighbourhood of 800 feet O.D. or possibly a few feet lower. What is probably another and considerable portion of the same feature is indicated by a nearly level shelf on the east side of the valley north of Trawsnant. Its lower margin almost coincides with the 800-foot contour-line, and, as it has a slight slope riverwards, the level of the old valley-floor was slightly below 800 feet. I have been unable to recognize with certainty any other traces on the sides of the present valley; but indirect evidence of an old floor at a considerable height above the river may be obtained in some of the tributary valleys, which join the Towy in the neighbourhood of Trawsnant, such as the Trawsnant stream itself, Nant Lletty-gleision, and Nant Brianne. The lower portions of these streams cascade over rock at the bottom of deep narrow ravines; but the ravines, when traced upstream, are seen to have been excavated in rather wide flat-floored valleys. In the Trawsnant stream (10·4) and Nant Lletty-gleision (10·3) the head of the ravine can be located closely. In Nant Brianne (11·0) this point is not so definitely marked, but it appears to be near the

ford at Henfaes; above this point the valley-sides are well graded, while below it there is a sharp discontinuity, especially on the north between the upper slopes and the precipitous sides of the ravine. The level of these lateral floors may be assumed to have been determined by that of the Towy valley at some former time.

Around Trawsnant and Bwlchyffin the sides of the Towy valley are steep, the floor is usually narrow, and the river lies mainly in a rock-channel. It may be noted also that the slopes below a level of about 1000 feet are considerably steeper than above that level, and the small streams which flow over the higher ground in graded valleys hang conspicuously above the main valley. This is well illustrated by a small tributary which enters from the west nearly opposite Bwlchyffin. Again, that place derives its name from two cols which occur close together west of the house at a level in the solid rock of about 875 feet, the ground north and south of the pair rising sharply to 1100 or 1200 feet. They are probably due to conditions under which two small streams, that rise near the eastern watershed of the Towy basin, flowed into the Towy through these cols, but have subsequently been diverted southwards along the strike-valley of Nantyffin. The river into which they flowed must have been at a level of 850 to 870 feet above O.D. Nantyffin turns westwards into the Towy near Ystradffin; but the wide valley in which it lies is prolonged southwards beyond the point where the stream turns into the Towy (fig. 6, p. 606). The highest point on its floor is 611 feet above O.D., or only a few feet higher than the junction of the tributary with the Towy. The extensive flat or 'Ystrad', to which Ystradffin owes its name, has been developed near their junction at a point where the escarpment of grey mudstones has been breached for a distance of about half a mile. This break in the escarpment, coupled with the wide dry valley leading from it, gives the impression that the latter was, at one time, the course of the Towy. At present, however, that river turns westwards through a narrow defile over 600 feet deep, which has been excavated in the hard basal rocks of the grey mudstone group. West of the defile it joins the Pysgotwr at 'Towy Rocks', but the two rivers are not at grade. The Towy slides over rocks and boulders in a magnificent cascade into the Pysgotwr, descending through a vertical distance of 60 to 80 feet in a horizontal distance of about 300 yards. In times of flood this cascade of foaming water is an impressive sight. Below Towy Rocks the valley opens out, its widening floor being covered with extensive glacial and alluvial deposits, among which, with a few exceptions between Rhandirmwyn and Llandovery, the river meanders until it reaches the head of the estuary at Carmarthen.

Near Rhandirmwyn the slopes of the valley are moderately steep, and at Galltyberau (13·3), Y Foel at the junction of the Gwenffrwd valley (14·2), and Allt Nantyronen above Towy Bridge, they are markedly concave and stepped in a manner suggestive of remnants of an old floor high above the present

valley. If, however, this be a correct explanation of these features, they afford no more than a rough indication of the former level of that floor.

IV. The Camddwr.

The Camddwr rises at a level of some 1600 feet, about a mile and a half south of Penybwlch, and flows on an almost straight course for $8\frac{1}{2}$ miles to join the Towy 6 miles north of Rhandirmwyn. Its valley may be divided into three regions. The first region includes the upper 3 miles of the valley, from its source to the neighbourhood of Rhydymeirch. The slopes are gentle and evenly curved, the floor is wide and covered with a level spread of Boulder Clay, and the spurs of the valley rising above the drift are set wide apart (see fig. 4). The river-channel is flanked by an alluvial floor of varying width cut in glacial deposits. Rock is rarely seen along its course, except above Nant y Maen (1·4) and at Ffrwd y Gamddwr (1·9), where a bar of massive grits has given rise to the waterfall of that name. Below the fall the valley-floor is at its widest, and the river meanders over an alluvial plain 100 to 150 yards wide. Throughout this reach of the valley the tributaries are concordant with the main river.

Fig. 4.—*The Camddwr Valley above Rhydymeirch, showing late-mature features.*

In the succeeding section, which includes approximately the next

3 miles from near Rhydymeirch to Rhydtalog (6·7), the floor is narrower, the slopes are steeper, and the glacial deposits diminish in amount. The opposing spurs are, therefore, closer together, and in a view up or down the valley they overlap distinctly. There is little indication of the U-shaped transverse profile which is so characteristic of the Towy valley near Nant Stalwyn, and they preserve almost unmodified their even convex form. Throughout a great part of this region the river lies in a narrow rock-channel, the depth of which corresponds approximately to the rise of the river in heavy floods. The majority of the tributaries are at grade with the main river; but those between Maes-glas (4·0) and Nant y Graig (5·0) are slightly discordant. It is in this region, too, that such traces as occur in this valley of a concave cross-section may be observed. Below Capel Soar (5·7) the rock-channel, in which the river lies, gradually deepens. On the west side is a wide platform which stands considerably above the level of the river, and in which the river-channel appears to have been incised.

In the lowest region of the valley, which is about $1\frac{3}{4}$ miles in length, and extends between Rhydtalog (6·7) and the confluence with the Towy (8·4), the river is confined in a rock-gorge, above which narrow platforms representing traces of an old valley-floor are occasionally preserved, as, for instance, near Rhydtalog, and, again, about half a mile below (7·2). Elsewhere the sides rise directly from the bottom of the gorge to a height of about 400 feet. On these exceedingly steep and, in places, precipitous slopes rock-scars alternate with shaly scree. The rapidity with which the traces of the pre-existing slopes and of the old valley-floor disappear in a short distance below Rhydtalog is remarkable.

V. The Doethie and the Pysgotwr.[1]

The Doethie Fawr rises a little below the 1500-foot contour, on the plateau east of Tregaron. Its chief source may perhaps be regarded as Llyn Berwyn. In its course of about $6\frac{1}{2}$ miles, before it joins the Pysgotwr, a mile and a half above the confluence with the Towy, it crosses obliquely the strike of the rocks. Its chief tributary is the Doethie Fach (2·8) which enters near Maes Bettws, and drains an area almost as large as does the main branch. Above the junction with this tributary the valley is relatively narrow, and the sides are steep. The slopes are even, and the spurs overlap distinctly. The channel is frequently rock-bound, and where it is crossed by grits they usually give rise to low cascades. The Doethie Fach and smaller tributaries are at grade with the river. About half a mile below the Doethie Fach the valley is exceedingly narrow, and its slopes, while still preserving their even outline, are steeper than upstream; but, a little lower

[1] The lower part of the Doethie valley is continuous in direction with that of the Pysgotwr, the profile of which is discussed in detail. In order to avoid the use of the expression of 'Doethie-Pysgotwr', I shall include this part of the Doethie in the Pysgotwr.

down, a progressive sharpening of the ends of the spurs may be observed, and near Nant Iwrch (3·4) the tributaries begin to hang above the valley-floor. In the next mile or so below this point the valley develops by insensible gradations into a straight deep groove with steep rock-scarred slopes, which rise to a height of about 400 feet above its floor. It maintains this character down to its junction with the Pysgotwr (6·4). The sides of the valley terminate abruptly upwards in a scar, above which smooth convex contours predominate. The tributaries hang considerably above the floor of the valley, as is well illustrated by Nant y Cnwch (5·3) which enters about a mile above the Pysgotwr. The upper three-quarters of a mile of the Nant-y-Cnwch valley nearly down to the 900-foot contour is well graded; but below that level the stream descends precipitously to the Doethie at about 600 feet. Other tributaries show the same abrupt contrast between the gradient of their upper and their lower portions.

In the Doethie the distinction between the lower and the upper parts of the valley is not so marked as in some of the other valleys, and the point where the change sets in cannot be closely located. It appears to lie between the Doethie Fach and Nant Iwrch.

The Pysgotwr rises at about the same level as the Doethie, and nearly 3 miles away to the south. East of Bonborfa (1·6) five tributaries of approximately equal length unite to form the main river. I regard Nant y Garn, which is slightly larger than the others, and is continuous in direction with the valley below, as the principal headwater. Each of these tributaries flows in a shallow valley, the slopes of which are of mature appearance. In the neighbourhoood of Bonborfa all the streams meander over a Boulder-Clay and peat-covered moorland which coincides with the outcrop of the soft shales in the axis of the Central Wales Syncline. Between that place and Nant Gwernog (3·4) the slopes of the valley are moderately steep, those on the south-west being somewhat steeper than those on the other side. A good deal of Boulder Clay lies on the floor, and conceals the lower flanks of the valley, so that the opposing spurs are set well apart. The channel is developed partly in rock and partly in these deposits. Just above Nant Gwernog the valley opens out considerably, and is covered by some depth of glacial drift; but between this place and the junction with the Pysgotwr Fach (4·5) it becomes decidedly narrower, and the river flows wholly in a shallow rock-channel. The tributary streams are, however, graded throughout, and the slopes of the Pysgotwr valley present the evenly-convex outlines characteristic of its upper reaches. Just above the mouth of the Pysgotwr Fach—a tributary which flows parallel to and a little south of the main river—the floor of the valley is trenched by a narrow gorge, which within a distance of 100 yards increases in depth to about 30 feet. A similar feature may be observed in

the valley of the Pysgotwr Fach. This gorge rapidly develops into the remarkable ravine which below this point takes the place of the mature valley above. The gradient around Bryn Ambor (3·8) is about 60 feet per mile; but below the junction with the Pysgotwr Fach the river descends over 300 feet in the same distance. In this valley, as in the Camddwr, it is remarkable how rapidly traces of the floor of the mature valley have been obliterated. Just below the junction of the two Pysgotwrs there is a well-developed narrow shelf at a level of about 880 feet, and a quarter of a mile below there is a wider remnant between the 800- and 900-foot contours, but there is no trace of this shelf lower down. There the slopes are rocky and steep: they do not, however, differ markedly in form from those bordering the mature valley above the junction with the Pysgotwr Fach. Nevertheless, a certain change in their character may be noted at a level of about 1000 feet, where the steep and rock-scarred valley-sides give place upwards to smoothly-convex grass-covered slopes which lead up to the surface of the plateau. These smooth slopes at the brow of the ravine are almost the only traces that remain of the older valley-sides.

VI. The Cothi-Gwenffrwd.

The Cothi rises at about the 1250-foot contour on the plateau 6 miles west of the Towy valley, and flows south-eastwards for about 3 miles. In this section the valley is wide, with smooth even slopes, and the opposing spurs are wide apart, a condition partly due to glacial deposits on the floor of the valley. Further, the tributaries are at grade with the main river. These characteristics may be recognized as far as Garthynty (2·4); but, near that point, the river winds for about 350 yards through a narrow gorge which forms a loop below the farmhouse. There is, however, no essential difference between the character of the valley above and immediately below this gorge, which may be looked upon as an accidental feature, a former channel being probably concealed under drift due south of the farm. Less than a quarter of a mile below the point where it emerges from the gorge (2·8) the river plunges into a narrow, almost straight ravine, carved in the floor of the old valley. The river descends in a series of cascades through a vertical distance of 240 feet in less than half a mile; then it turns almost at right angles towards Aber-Branddu. The old valley is well preserved on each side of the ravine; but, instead of turning south-westwards with the river, it continues eastwards, gradually increasing in width, past Bwlchyrhiw. Near that place it is, however, almost dry, being occupied only by a tiny stream called Nant Cartws, which descends the steep slope from Crugiau Ladies, and then flows sluggishly along the flat marshy floor of the valley. West of Bwlchyrhiw another streamlet flows back, to fall over the edge of the ravine into the Cothi. The watershed between the eastward-

and westward-flowing drainage is near Bwlchyrhiw, and at a level of 854 feet above O.D. Nant Cartws reaches the floor of the valley almost on the watershed, but is too insignificant to have given rise to a delta or corrom. At the foot of the slope it has cut a channel a few inches deep in Boulder Clay, and at one point a slight obstruction would cause it to flow westwards towards the Cothi—in fact, it appears at times to do so, but at the time of my visit it was prevented from taking that course by a few clods of earth which had been put there for the purpose.

The floor of the valley in the Bwlchyrhiw gap is covered by a considerable depth of Boulder-Clay; but, between the col and the edge of the Cothi ravine, rock is exposed a few feet above the 800-foot contour, and, again, about half a mile east of the col at a little below 800 feet. The rock-floor of the gap appears, therefore, to slope eastwards from the edge of the ravine, and its level is such that the river occupying the old Cothi valley would naturally flow that way. Near Capel Bwlchyrhiw a tributary named Nant Melyn enters from the north, and at this point there is a steep descent towards the lower part of the valley, where the principal river, the Gwenffrwd, enters. The old valley in the Bwlchyrhiw gap hangs distinctly above the present floor of the Gwenffrwd, and at the bend west of Bwlchyrhiw it lies more than 100 feet above the bottom of the Cothi ravine. The upper parts of the Nant Melyn and Gwenffrwd valleys also hang above the lower part of the Gwenffrwd valley, so that both the lower Gwenffrwd and the lower Cothi valleys have been carved in the floor of an older valley, which has thus been attacked at two distinct points. From Capel Bwlchyrhiw to the Towy the Gwenffrwd valley widens gradually, and an increasing depth of glacial and alluvial deposits covers its floor. It resembles in its essential features the lower part of the neighbouring Doethie valley.

VII. Base-Levels of the Valleys.

That the existing Towy valley as far up as the neighbourhood of Fanog has been excavated in the floor of a pre-existing valley is supported by the clearest evidence. At the point where the river passes from the old into the new valley there is a change in the valley-slopes and in the gradient of the river, so abrupt that it may be described as a topographic unconformity. The gradient near the source of the river is nearly 250 feet per mile, but diminishes to about 40 feet per mile above Fanog, where it suddenly increases to something like 200 feet per mile, thereafter diminishing continuously to about 2 feet per mile in the tidal region at Carmarthen. A gradient equal to that above Fanog is only reached again $5\frac{1}{2}$ miles below. In a similar manner, the relatively gentle slopes of the old valley give way suddenly to the precipitous sides of a ravine, and slopes of the same inclination as those of the old valley do not occur again for some distance down the valley.

The discontinuity in the topographic features of the valley shows most clearly in the longitudinal profile. The discontinuity in the transverse profile or cross-section is more rapidly obliterated, and a few miles below Fanog it is difficult to discover that the valley-slopes have been refashioned.

Along the Pysgotwr the change from the old valley to the new is even more sudden; near Pysgotwr-fach the contrast between the smooth slopes of the old valley and the rock-scarred precipitous sides of the newer valley is remarkably striking.

On the Camddwr the features of the lower part of the valley near its junction with the Towy are very distinct from those above Capel Soar (5·7) about 2 miles up, and still more distinct from those below Maesglas (4·3). The average gradient near the latter place is about 55 feet per mile: it is decidedly steeper for the next 2 miles, amounting on the average to about 80 feet per mile; but, between 6·6 miles and the junction with the Towy, the average gradient is nearly 120 feet per mile. There is, therefore, a pronounced steepening of the profile in the lower part of the valley; but there is no abrupt transition as in the Towy and Pysgotwr, and it is difficult to locate precisely when these changes set in.

On the Doethie the change is still less marked, and appears to occur higher up the river than in the adjoining valleys, so that more of the old valley has been removed.

In the Cothi valley the discontinuity is quite as pronounced as in the Towy or Pysgotwr; but the relationship of the present to the pre-existing valley is, in that case, complicated by the diversion of the river into a new course.

The change in each valley can be attributed to rejuvenation brought about by an elevation of the area, whereby the river-gradients have been greatly increased, thus leading to renewed erosion of the valleys.

Between Carmarthen and Llandovery the Towy is graded with the existing sea-level, and the tributaries which enter it are at grade with the main river; but from Llandovery to Fanog the graded condition has not been fully attained.

The valley above Fanog is not graded with that below, and appears to have been fashioned at a time when the level of the land stood relatively lower than at present. The tributaries which enter above the point of rejuvenation are, with minor exceptions, approximately graded with the old valley; but below that point, as will be shown later, only the upper part of each tributary valley above its own point of rejuvenation appears to have been graded with the old Towy valley.

In this region, therefore, we have evidence of two distinct base-levels corresponding to two different cycles of erosion. The lower portion of each valley has been determined by the existing level of the sea as a base-level, while the upper portions of the valleys are related to a different and older base-level. In order to avoid confusion and cumbrous description, these levels will be referred to as the L l a n d o v e r y and F a n o g base-levels respectively.

By an analysis of the longitudinal profiles of the main river and its principal tributaries above Rhandirmwyn, I have attempted to determine as nearly as possible the ancient base-level and thereby to reconstruct the old drainage-system which has been to a great extent destroyed by subsequent erosion.

As will be shown below, there is some reason to infer a third base-level to which the uppermost regions of the valleys correspond. This will be referred to as the Nant Stalwyn base-level.

The Longitudinal Profiles.

The Towy.—The profile obtained by plotting the levels of points on the floor of the valley against the distance from the source measured along the mean course of the valley is a rather irregular curve, in which short reaches of relatively high gradient alternate with longer reaches of lower gradient; but, despite numerous irregularities, it is obvious at a glance that the average gradient diminishes downstream, since a smooth line drawn through the levelled points so as to represent the average level of the valley-floor is a concave curve which steepens rapidly towards the source of the river. The average gradient at any point in the valley can be determined by estimating from this curve the level of the floor at numerous points—say, at each fifth mile—and dividing the difference between adjoining points by the distance between them.

If the values of the gradient so obtained are also plotted, and a smoothed curve drawn through the points, the change in the gradient is strikingly shown. It diminishes rapidly in the first 2 miles of the valley, and thereafter much more slowly.

Considerable differences are revealed between the actual level of the floor and the average profile represented by the smoothed curve. The reason for these differences need not be considered at this stage, but it is obvious that the river is not in complete adjustment with the valley-floor. In those parts of the valley where the floor is above the average level the river is confined in a narrow rock-channel where active erosion is in progress. In the intervening reaches its channel lies in gravel, and is bordered by a varying width of alluvial deposits, so that the river there has the appearance of being fully graded. Each rock-barrier serves as a temporary base-level for the graded reach immediately above, and with its progressive lowering the grading of the upstream reach keeps pace with the changing base-level. The profile is, therefore, approaching closely to the graded condition, and, when the river has worn down its rock-channels by a few feet, the level of the valley-floor will not depart sensibly from a smooth curve, drawn so as to pass through the majority of the points in the existing graded reaches. The amount by which the rock-channels must be lowered to attain this profile varies from 4 to 12 feet in the lower region (between 4 and 8 miles) and from 14 to 22 feet in parts of the upper region (between 2 and 4 miles).

As regards the lower region, it is probable that in pre-Glacial times a mature profile had been attained, and that the existing

irregularities have been caused in various ways by the subsequent occupation of the valley by moving ice; but, as regards the upper region, especially between 3 and 4 miles, there probably was an abrupt change in the level of the valley-floor, which has been partly reduced or toned down by glacial erosion. The evidence which is discussed on p. 598 leads to the conclusion that the pre-Glacial profile of the Upper Towy consisted, in fact, of two mature reaches, separated by a step in the valley-floor which was in process of being lowered by river-erosion. These two reaches correspond to two periods of base-levelling. The irregularities in the longitudinal profile are, however, of minor importance in comparison with the size of the valley, which on the whole presents a thoroughly mature aspect with relatively smooth convex slopes. We may, therefore, assume that the smooth curve drawn through the graded reaches represents the form of the mature valley that will in time be excavated in these slaty rocks by the Towy. Such a curve gives a closer approximation to the fully-graded profile of the valley than one which represents the average level of the valley-floor. It is possible, however, that in the fully mature stage the profile would be slightly more concave than this curve. This is suggested especially by the fact that the gradients between 4 and 6 miles are, on the whole, in excess of a smoothed gradient curve.[1] The slopes of all the tributary valleys are similar in form to those of the main valley, and their floors have been eroded to a concave profile, so that we are clearly dealing with a drainage-system in a mature stage. The mature valley persists down to the point where active erosion of the floor and slopes is in progress. Even below that point, in most of the valleys, there are more or less obvious traces of the pre-existing valley-floors. As there is no reason to believe that the profiles of the valleys above their points of rejuvenation have been altered by the subsequent erosion of the valley below, the mature valleys must have existed substantially in their present form since the time when they were graded during a former period of base-levelling. It is probable, however, as suggested above, that some modification of their floors and slopes may have been produced by glacial erosion.

The smooth curves obtained in the manner described above, which represent (*a*) the level of the valley-floor at increasing distances from the source, and (*b*) the gradient of the valley, indicate that the levels and gradients steadily diminish downstream, or (in other words) that the valley becomes lower and markedly flatter in that direction.

The detailed form of these curves is probably determined for each river mainly by the volume of the river during flood. The nature of the channel, or of the deposits in which it is excavated, may also exercise some influence. These deposits vary in size, from large boulders down to fine mud, and the form of the longitudinal profile reveals the gradient required by each river to transport its normal load. The volume of a given river depends upon the area

[1] See Gradient Curve, Pl. XLIV.

of the watershed, the rainfall and the 'run-off'; the flattening of the profile downstream is undoubtedly related to the increase of volume which goes with increase of the drainage-area.

It is important to bear in mind that the profiles that we have been discussing are those of the existing rivers in relation to their present circumstances; but, if next we proceed on the hypothesis that the ancient Towy river which excavated the mature pre-Glacial valley, especially between Fanog and Nant Stalwyn, had the same profile as the existing river, we can by extrapolation reconstruct the ancient valley in the region below the point where it has been destroyed by rejuvenation, and also obtain an estimate of the present height above sea-level of the ancient base-level. It cannot, however, be assumed without some knowledge of their régime that the ancient rivers had the same profile as their present-day successors, since their volume and load may have been different. The influence of these factors is discussed below.

In the absence of information regarding the form of the rock-floor in pre-Glacial times the relation which the profiles of the existing rivers bear to those of their predecessors cannot be accurately determined. We find, however, that each river encounters rock in innumerable places, not only at the side of the valley but in the centre as well, which may be interpreted to mean that the cover of superficial deposits is in general of limited thickness, and that the present profile of the rock-floor coincides approximately with the profile of the flood-plain. Further, there is no reason to believe that the glacial excavation was so severe as to invalidate the assumption that the profile of the ancient valley was not materially different from that of the recent valley. It is true that in parts of the valley there are rock-steps which indicate inequalities in the floor; but, in comparison with the width and depth of the valley, they are of inconsiderable dimensions.

If we can succeed in finding a mathematical expression to which the profiles of the existing rivers conform, those profiles can be prolonged by extrapolation and thus afford a means of reconstructing the floors of the ancient valleys which have been destroyed by erosion. Moreover, the base-level to which the ancient drainage-system was graded can be approximately determined. In applying this method we can make use of the principle that in a mature system the level of the flood-plains of a tributary, and of a main river at their junction is approximately the same. The rock-floors are not, in general, accordant, because the depth of river-deposits in the main valley is usually greater than in the tributary valley; the discordance is, however, comparatively small, and corresponds to the difference in the rise of the two rivers during floods.

The extrapolated profile of a tributary should, therefore, give nearly the same level for the ancient valley-floor at the junction as does that of the main river. There is probably also some relation between the gradient of a tributary and that of the main river at the point where they meet; the nature of this relation has

not, so far as I know, been determined. If the law connecting the gradients were known, a further important principle would be available for the reconstruction of the old valleys. The appearance of the river-profiles published by A. Penck,[1] G. de la Noë,[2] and others, suggests that the profile of a main river is an envelope to those of the tributaries, in which case all the curves should have a common tangent at their junction, or (in other words) should have the same gradient at these points. This is almost certainly not the true relation; rather there appears to be some evidence of a discontinuity at the junction of a tributary with the main river and that the gradient of the former is, in general, higher than that of the latter, the difference increasing with the difference between the volumes of the rivers. This is more evident in small tributaries than in large; the alluvial cone of a small stream debouching on a wide valley-floor has usually a well-defined margin, and rises sharply out of the flood-plain of the main river.

The appearance of the profile suggests that it might be expressed by either a parabolic, a hyperbolic, or a logarithmic function: and various forms of all these functions have been tried. The best expression appears to be that which was suggested by the form of the gradient curve, which resembles a rectangular hyperbola. This curve can be expressed by the formula $(x+a)(g+b)=k'$, where x is the distance measured from the arbitrary origin of the river, g is the gradient $\frac{dy}{dx}$, and a, b, and k' are constants (a and b may be positive or negative). It is found, in fact, that a formula of this type gives a fairly close representation of the gradient in different parts of the valley, and (if the expression be integrated) we obtain an expression of the following form for the profile:—$y=k \log(x+a)-b(x+a)+c$, where x, a, and b have the same significance as above, y is the height of the valley-floor above Ordnance Datum, and k and c are new constants. This represents a logarithmic curve on which is superposed a straight line, or, in other words, a logarithmic curve referred, not to a horizontal, but to an inclined datum-line. The logarithmic component is the more important for moderate distances from the origin. The corresponding gradient, g or $\frac{dy}{dx}$ is given by the expression $g=\frac{k'}{x+a}-b$ where $k'=k \log_{10}e = \cdot 434k$, or $(g+b)(x+a)=k'$. Since the value of y diminishes with increasing values of x, the gradient is negative, and, since $x+a$ is positive, then k' and k must be negative. The constant $c=Y-b$, Y being the value of y when $x+a=1$; but, since b is in general small, c is approximately equal to Y. The expression is best used for purposes of calculation in the following form:—

$$y=c-k\log(x+a)+b(x+a).$$

[1] 'Morphologie der Erdoberfläche' 1894, p. 323, fig. 23.
[2] G. de la Noë & E. de Margerie, 'Les Formes du Terrain' 1888, pl. xviii.

The disadvantage of the expression is that, unless b is zero, the gradient does not vanish for infinite values of x. This would appear to be a necessary condition, since the main river ultimately flows into the sea where the gradient is sensibly zero; but if, as suggested above, there is a discontinuity of gradient where two bodies of flowing water unite, the smaller body may retain a perceptible gradient up to the point where it becomes merged in the larger body. Another disadvantage is that the value of the constants can only be obtained by trial. This has been done by first constructing a smoothed gradient curve, and, on the assumption that it is a rectangular hyperbola, finding an approximate value of a from this curve. The other constants corresponding to that value of a, and also other values differing from it by small amounts, were then determined by calculation. For each set of constants so obtained the values of y for a number of points along the valley-floor were calculated, and compared with those read off directly from the curve. That value of a which gave the closest agreement, especially in the lower part of the profile, was selected for the purpose of extrapolation.

If b is assumed to be zero, an approximate value of a can be obtained directly, and the substitution of this value of the constant in the formula gives approximate agreement with the curve; but a better result is, in general, obtained when a slightly different value of a, is used. The gradient curve was constructed by determining from the smoothed profile the level of the valley at each tenth mile, taking the difference between alternate pairs corresponding to a distance of one-fifth mile, and plotting the resultant gradient against the values of x corresponding to the middle of each interval. A smoothed curve was then drawn through the points so obtained (see Gradient Curve, Pl. XLIV).

The three points $x = {\cdot}5$, $4{\cdot}5$, and $8{\cdot}5$ measured in miles from the arbitrary origin selected were used in finding the constants. The constant b is zero for a value of $a = 1{\cdot}86$, but a closer correspondence with the smoothed profile is obtained when a is somewhat greater than this figure. The following table (I)

Table I.

Values of the constants c, k, and b for different values of a in the expressions

$$y = c + k \log (x+a) + b\,(x+a) \text{ and } g = -\frac{dy}{dx} = -\frac{k'}{x+a} - b.$$

a	0·6	0·9	1·2	1·8	2·0	2·4
c	1462	1522·3	1590·6	1742·5	1797·8	1915·8
k	−487·6	−578·8	−679·1	−892·4	−967·6	−1124·4
b	−17·02	−12·66	−8·3	+0·13	+2·88	+8·32
k'	−211·78	−251·39	−294·24	−387·57	−420·23	−488·33

shows the values of c, k, and b in the above expression for varying values of a. The succeeding table (II) is a summary of

TABLE II.

y calculated for different values of a and differences from curve.

x.	y obtained from curve.	·6	Diff.	·9	Diff.	1·2	Diff.	1·8	Diff.	2·0	Diff.	2·4	Diff.
1	1331	1335·3	4·3	1336·9	5·9	1339·8	8·8	1314·8	13·8	1344·8	13·8	1346·5	15·5
2	1215·5	1215·4	−0·1	1217·9	2·4	1221·0	5·5	1225·6	10·1	1226·8	11·3	1228·9	13·4
3	1134	1129·4	−4·6	1130·8	−3·2	1132·5	−1·5	1135·2	1·2	1135·9	1·9	113·72	3·2
4	1063	1060·5	−2·5	1060·7	−2·3	1061·2	−1·8	1061·9	−1·1	1062·2	−0·8	1062·6	−0·4
5	1000	1001·9	1·9	1001·4	1·4	1001·0	1·0	1000·4	0·4	1000·3	0·3	1000·0	0·0
6	947	950·1	3·1	949·4	2·4	948·6	1·6	947·4	0·4	947·1	0·1	946·4	−0·6
7	901	903	2·0	902·7	1·7	901·9	0·9	900·7	−0·3	900·5	−0·5	899·8	−1·2
8	859	859·9	0·9	860·1	1·1	859·7	0·7	859·2	0·2	859·1	0·1	858·8	−0·2
9·6	(Camddwr)	796·6		798·3		799·2		800·8		801·3		802·2	
12·3	(Pysgotwr)	700·8		706·6		711·0		718·7		723·7		725·6	
56	Mouth of Towy	−352		−214		−77·6		177·6		258·8		415·6	
Sum of differences			19·4		20·4		21·8		27·5		28·8		34·5
Sum of differences between 5 & 8			7·9		6·6		4·2		1·3		1·0		2·0
Gradient at the mouth of the Pysgotwr		33·5		31·8		30·2		27·4		26·6		24·9	
Levels in feet if the rivers met at Towy Rocks		684		691		696		705·5		708		713·5	

the results obtained by the use of various constants; it shows the value of y corresponding to the mile-points between 1 and 8 miles from the origin, and the difference between the calculated value for each point and that obtained from the curve. The calculated levels of the reconstructed Towy valley at the points where the Camddwr and Pysgotwr enter, and also at the mouth of the present river below Carmarthen, are also given. The level of the old valley at its junction with the Pysgotwr is calculated on the assumption that the two rivers met above the Ystradffin gorge. The level at the junction has also been calculated on the assumption that they met at Towy Rocks as they do at present. For comparison with the tributaries, the gradient of the Towy at its junction with the Pysgotwr on the first of these assumptions is shown.

It will be seen from the table that, while all values of a give levels of the valley-floor between the third and the eighth mile that differ by only a few feet from the curve and in some cases differ only by inches, no value gives a satisfactory agreement at the first mile and only the smaller values at the second mile. Greater importance is attached, however, to close agreements with the lower part of the curve, since our confidence in reconstructing the old valley by extrapolation is increased in proportion to the degree of accordance between the calculated and the smoothed profile in the lower region. In this respect there is little to choose between the values of a in the last three columns, for each of which the average difference lies between 0·3 and 0·5 foot, which are within the limits of error of plotting of the results, and the individual differences are somewhat irregular, some values being too large, others too small.

From these results we find that the level of the ancient valley-floor at its junction with the Camddwr varies between 796·5 and 802·2, the most probable value being just above 800 feet. This confirms the interpretation of the shelf near the junction of these valleys which stands at 800 feet above Ordnance Datum as a remnant of the old floor. The level of the present valley-floor at that point is 685 feet, or 115 feet lower. Similarly, there is no great difference between the extreme values for the level of the Towy–Pysgotwr junction which range from 700·8 to 725·6. We may take 723·7 or 725·6: namely, those given by the curves for which $a=2{\cdot}0$, or $a=2{\cdot}4$, as being nearest the true values. The existing valley-floor is 265 feet lower: that is, about 460 feet above Ordnance Datum. The difference between the old valley-floor and the present valley thus appears to increase at the rate of about 50 feet per mile; but it is evident that it cannot continue to increase at this rate. On the other hand, the difference will not become smaller downstream unless, as is unlikely, the gradient of the old floor was steeper in that direction than that of the present floor. A rough approximation to the base-level of the old valley-system

is thus obtained. It now stands at least 265 feet higher than the present sea-level.

If we attempt to determine by extrapolation the values of y at the present mouth of the Towy, 56 miles from the origin, slight differences in the value of a give rise to wide divergences in the level of the old floor at that point. Thus, for $a=1{\cdot}8$, $y=178$; for $a=2$, $y=259$; and for $a=2{\cdot}4$, $y=415{\cdot}6$. The first two figures are (as shown above) too low, and the last may be too high, but rough limits are thus obtained.

A closer approximation to the ancient base-level can be obtained by making use of the profile of the present river as a control in extrapolating from the upper part of the curve. Between Rhandirmwyn and Llandovery the Towy is, in places, confined in a narrow rock-gorge. At those points active erosion is in progress, and the profile has not acquired its final form; but between Llandovery and Carmarthen the river meanders through a wide alluvial plain, and its profile has attained stability.

The values of y along the ancient valley have been calculated for $a=2$ and $a=2{\cdot}4$ from the head of rejuvenation above Fanog to the mouth of the Towy 6 miles below Carmarthen, and the profile of the present valley-floor between the Towy–Pysgotwr junction and the same point has been constructed from the contour-lines and spot-levels on the 1-inch maps. The flood-plain at the mouth of the river is about 13 feet above O.D. The latter profile was copied on tracing-paper, and compared by superposition with the two calculated profiles, the base-lines being kept parallel. The curve for $a=2{\cdot}4$ coincides with the recent profile between 30 and 38 miles; above 30 miles the recent valley-floor has a higher gradient, as might be expected, since in that region it is in process of being lowered by erosion. Below 38 also the recent valley has a slightly higher gradient than the curve; but, if we assume that the calculated curve is not seriously in error at 30 miles, and that thereafter it has the same profile as the present floor, it would stand at the mouth of the Towy at 397 feet above O.D. A well-graded river traversing an area deeply covered by the products of rock-decay would probably have a flatter profile than the present Towy, wherefore this figure may be too low. The value of y at that point obtained by calculation from the formula is $415{\cdot}6$, corresponding to an ancient 'Ordnance Datum' of about 403 feet.

With the value of $a=2$, coincidence between the two profiles is obtained between 22 and 28 miles, but the fit is evidently less satisfactory than with the previous curve: especially below 28, where the recent valley has a considerably lower gradient. Assuming that the calculated profile is approximately correct at 22 miles, and is replaced below that point by the recent profile, the ancient valley-floor at the mouth of the Towy would stand at 350 feet above Ordnance Datum: the value given by the curve is 259 feet. These values are certainly too low, those obtained from the previous curve being probably nearer the truth.

We thus arrive at the conclusion that the ancient base-level is now at least 384 feet, and possibly as much as 403 feet, above its former level.

We arrive at somewhat similar figures by using the recent profile as a control in another way. After the gradient of a mature valley has attained a given value, it diminishes downstream according to some law that is characteristic of the river. This law may be expressed approximately, as shown above, by a formula; but, as there are points in the present valley (say, near Rhandirmwyn), which have the same gradient as the old valley above Fanog, the law of change of gradient may also be obtained by superposing a part of the recent profile on some part of the profile above the head of rejuvenation, so that they coincide for a certain distance (the base-lines of the two profiles being kept parallel as before). There is, therefore, no extrapolation of the ancient valley, since the prolongation downstream of the profiles of the old valley is assumed to be the same as that of the recent profile. The result is interesting: it is found that, by superposing point 12·8 of the recent profile on 8·2 of the ancient profile—that is, a third of a mile above where the ancient valley is being eroded away,—the profile calculated from the formula in which $a=2{\cdot}4$ does not depart anywhere from the recent profile by more than 10 feet beween 8·2 miles and Carmarthen, a distance of about 40 miles. The average departure is $3\frac{1}{2}$ feet. The formula gives, therefore, an almost exact representation of the form of the recent profile for a distance of over 40 miles, and it is clear that (although it is based on information derived from points only a few miles from the source) it summarizes the behaviour of the river many miles below with some exactness. In order to produce the superposition of the curves, the base or Ordnance-Datum line of the recent profile has to be raised 414 feet; and this figure gives another estimate of the difference between the ancient and recent sea-levels. The superposition has been done in another way by making use of the gradients. Those of the old valley were calculated from the formula for two values of a (2 & 2·4) and plotted against the distance from the source. The curves so obtained were traced and superposed on the gradient-curve of the recent profile, so as to bring some one point where the gradients were the same into coincidence. If the two curves then fitted closely, it followed that the gradients at the other points downstream were the same, or, in other words, the two profiles had the same form. It was found that, by bringing the gradient corresponding to point 10·5 on the old profile ($a=2{\cdot}4$), to coincide with that at point 15·2 on the recent profile, the two curves fitted closely. The level at point 10·5 is 774 and at 15·2 it is 362, the difference being 412, thus agreeing very nearly with the previous result. The last two values are believed to be somewhat too high, as, by the method of superposition employed, a part of the river which has a large volume is

superposed on a part which has a smaller volume. For example, the gradient at the lower point 15·2 will ultimately be lower than it is at present when the valley above Llandovery has been more perfectly graded, so that, in order to obtain the same gradient as at 10·5, a part of the recent profile lying higher upstream (and, therefore, at a greater height above O.D.) would have to be superposed on the ancient profile, and a smaller difference between the levels at that point would result.

If the same process is attempted for the curve in which $a=2$, it is impossible to obtain coincidence of either the profile or the gradient curves for more than a short distance, and it is clear that this curve represents much less closely the characteristic behaviour of the river than the curve obtained from the higher value of a.

Summarizing these results, we find that the base-level to which the ancient Towy drainage-system was graded now stands at a height of between 384 and 414 feet above the present sea-level. The latter value is probably too high, and the former possibly too low; but these studies have made it possible to define the change in base-level within very narrow limits.

The argument rests, however, on two important assumptions: (1) that the ancient river was comparable in (*a*) its volume and (*b*) the nature of its load with the present river; and (2) that there has been no tilting of the area subsequent to the grading of the mature valleys which are now preserved in the Upper Towy system. There is abundant evidence that the ancient valleys had been destroyed by erosion for a distance of nearly 50 miles above the mouth of the present Towy before the advent of the Glacial Epoch, and that the displacement of the point of rejuvenation upstream by Glacial or post-Glacial erosion has been relatively trifling. The change of base-level which caused the rejuvenation must, therefore, have occurred long before that epoch. The lower region of the ancient valley had reached its mature stage before the rejuvenation commenced, and must have been fashioned during some part of the Tertiary Era.

As regards the volume of the river which eroded it, the effect of the rejuvenation has apparently enlarged somewhat the drainage-area of the Towy system at the expense of that of neighbouring systems, and a tributary such as the Cothi has undoubtedly suffered considerable changes; these have had the effect of diverting some of the water which flowed into the ancient river near Rhandirmwyn, so that it now enters the Towy many miles lower at Nantgaredig. It is believed, however, that the change in the area of the drainage-system as a whole was probably small.

The volume of a river depends on other factors than the drainage-area. Among these the rainfall is the most important, and, although it is not possible to estimate the rainfall of the Tertiary Era, general considerations suggest that it was lower

than at present, owing to the smaller relief. On the other hand, the area may have been nearer the sea than at present, a circumstance which might or might not increase the rainfall, or the climate may have been radically different, perhaps tropical or sub-tropical. A smaller rainfall on the same area as that of the existing drainage-system connotes a smaller volume in the river, which would, therefore, require a higher gradient to enable it to carry the same kind of load as the existing river. Further, with lower relief, the run-off would be less than at present; while, if the area were under tropical conditions, an abundant vegetation would also affect the run-off.

As regards the load, the maturity of the ancient drainage-system denotes a long preceding period of denudation, during which the rocks of the area were covered by a thick mantle of weathered products. The type of material carried into the ancient rivers would, therefore, probably consist largely of fine silt and mud; while the recent rivers derive their load to a great extent from glacial materials which are (on the whole) much coarser than the products of rock-decay. It may, therefore, be assumed with some confidence that the load was of finer grade than at present, and would require, therefore, a smaller gradient for its transportation. The influence of a probable smaller rainfall and of a probable finer load are in opposite directions, and, as a first approximation, we may assume their effects to balance.

The second assumption made above is a more serious one, and for its full discussion a much larger region than is dealt with in the present investigation would have to be taken into account. I hope to return to the consideration of this problem when opportunity offers; but, for the present, it is assumed that no tilting has occurred. It appears, however, that, so far as can be discovered within the limits of the Upper Towy drainage-system, the combined effects of the conditions discussed above have been such as to leave the mature valleys, with minor exceptions, of such a form that the present rivers find them adapted to their needs without serious modification. On the other hand, it is possible that, even if a tilting of the old valleys had occurred subsequently to their formation, little change of their form by the present rivers would take place above the head of rejuvenation, so that (in the upper reaches of a valley) the effect of an uplift accompanied by tilting might be difficult to distinguish from that of a simple uplift.

As I have shown that the main features of the Towy valley below Fanog can be accounted for by stream-erosion following an uplift of the area in pre-Glacial times, it remains to consider certain other features which have been mentioned already, but were passed over as being of subsidiary importance. These include (1) inequalities in the rock-floor of the valley which have been designated as rock-barriers and rock-steps; and (2) hanging tributaries entering the main valley above the head of rejuvenation.

VIII. Rock-Steps and Hanging Valleys.

The rock-steps and hanging valleys appear to stand in a systematic relation one to the other and may, therefore, be considered together. The most marked drop in the floor of the Towy valley occurs about half a mile above Nant Stalwyn, where the river emerges (4·1) from a narrow gorge. The flood-level in this gorge stands in places 20 to 25 feet above the profile which has been drawn through the graded reaches of the valley, and the gorge has been excavated in the floor of a narrow valley of mature aspect which stands another 20 to 25 feet above the flood-level. The rock-floor in this locality is, therefore, from 40 to 50 feet at least higher above the smoothed profile than it is in the graded reach immediately below. The tributary Nant Tadarn, which enters from the east just below the gorge, cascades into the Towy for a distance of about 300 yards; and its valley-floor, if prolonged, would stand 30 to 50 feet above that of the Towy smoothed profile, and would thus appear to be at grade with the valley-floor above the rock-step. Another tributary, Hirnant (4·3), which flows in from the west is more conspicuously discordant. For about 400 to 500 yards above its mouth the stream is in a narrow chasm about 20 to 30 feet deep eroded in the floor of a V-shaped valley which, before the gorge was cut, had a steep fall towards the Towy. Apart from detailed levelling, the only means of estimating the hang of this valley is given by the points where the 1500- and 1250-foot contours cut the stream, and they show a hang of anything between 40 and 100 feet.

Lower down, Nant y Gerwyn (5·0) behaves in a similar manner. If the average gradient between the 1250-foot contour and the Towy valley remained the same as between it and the 1500-foot contour, the valley would have a hang of 45 feet. On the more probable assumption of a diminished gradient in its lower course the hang might be as much as 120 feet. Above the intersection of the stream with the 1250-foot contour the valley is wide and of thoroughly mature aspect. Below that point it is narrow and steep-sided, but its form is typically that of a stream-eroded valley.

The valley of the Maesnant stream (5·6) near Nant yr Hwch is estimated to hang about 40 to 80 feet above the Towy valley, while Nant Cwm-du, which formerly entered at 6·2 but, owing to diversion now enters at (6·0), and Nant y Fleiddiast, both appear to grade with a level considerably above the main valley. The discordance between the hanging tributary valleys and the Towy floor thus increases, on the whole, downstream.

An abrupt fall in the valley-floor such as occurs above Nant Stalwyn, combined with a series of hanging valleys below that point, constitute features which have frequently been attributed to glacial erosion; and the form of the valley, especially near Nant Stalwyn, lends considerable support to a similar explanation in this case. The flanks of the valley are decidedly concave,

with a smoothed appearance suggestive of intense glacial erosion, and in places the rock-surfaces are well striated. Moreover, the tributaries above the rock-step also hang, but not to the same extent as those below. Thus, the Maesnant tributary grades with a level about 15 feet above the present valley-floor, and both Nant yr Ergyd and Nant y Bont (3·5) cascade over rock for a distance of about 300 yards, indicating a steepening of their gradients near their mouths.

It is undeniable that some glacial erosion of the valley has taken place, and the facts so far stated are consistent with differential erosion of the floor and widening of the valley by scouring its flanks. There are, however, other facts which tell strongly against this explanation. The lower ends of the tributaries flow in **V**-shaped valleys which are narrower than upstream, and have in most cases a markedly steeper gradient for the last one-third or half-mile of their course. In some of them the narrow chasm which may be attributed to post-Glacial stream-erosion can be readily distinguished from the **V**-shaped valley, the excavation of which was far advanced before the advent of the Glacial Epoch.

If the discordance between the floors of the tributaries and of the Towy had been produced by overdeepening of the latter and concurrent removal of the lower ends of the tributary floors, as described by Dr. A. Harker[1] in the Cuillin Hills, then the pre-Glacial valley should end at the edge of the Towy valley, and the tributary, apart from any post-Glacial erosion which may have occurred, should descend over a smooth glacially-eroded surface. This is contrary to the facts in this valley, since the tributaries begin to hang at a distance of from a third of a mile to half a mile from the edge of the Towy valley. Moreover, the general movement of ice in the region was not in the direction of the valley. The striæ on the rock-surfaces near Nant Stalwyn point directly across the valley; but, although this may be exceptional, the distribution of the conglomerate erratics (see p. 574) on the slope east of the Towy points to the same conclusion. The conditions were, therefore, not favourable for effective glacial erosion, and it is more probable that the hanging valleys are, in the main, the result of an earlier uplift which caused rejuvenation of the main valley and of the tributaries. On this view the rock-step above Nant Stalwyn may be regarded as the head of rejuvenation, brought about by this uplift.

The valley above the Nant Stalwyn rock-step must, then, be the product of a period of base-levelling earlier than that to which the valley between Nant Stalwyn and Fanog corresponds.

There is, again, some evidence farther down the valley of two distinct periods of base-levelling. The Trawsnant stream (10·4) east of the road from Bwlchyffin to Fanog lies in a valley of late-mature aspect, with a broad flat floor and gentle slopes. West of

[1] 'Ice-Erosion in the Cuillin Hills (Skye)' Trans. Roy. Soc. Edinb. vol. xl (1901) pp. 221–52.

the road the stream enters a narrow ravine, on the north side of which there is a flat floor continuous with, but narrower than, the old valley above (see fig. 5). The gradient of the stream in the ravine is at first moderate; but, before reaching the Towy, it becomes precipitous, and the profile of the stream shows two distinct changes of gradient. The lowest reach near the mouth of the tributary is approximately at grade with the present river; the middle reach, if prolonged to the Towy, would stand at about 780 feet—that is, nearly at the same level as that deduced from the profile of the old Towy floor; but the upper reach (if similarly

Fig. 5.—*The Trawsnant tributary valley, showing rejuvenation of a late-mature valley.*

prolonged) would stand at a level of about 890 feet. The aspect of the upper reach proves that it must have formed part of a drainage-system in a late-mature stage of development.

The tributary Nant Lletty-gleision (10·3) on the opposite side of the valley shows similar features. The mature floor is preserved to just below the 1000-foot contour, and, if it had a uniform gradient equal to that between the 1000- and the 1250-foot contours, it would stand at 820 feet in the Towy valley. If we make a reasonable allowance for a diminution of gradient downstream, a more probable figure of 880 feet is obtained.

More striking evidence is furnished by the two cols at Bwlchyffin (near 11·3), mentioned on p. 579. The rock-floor in both is

almost exactly at the same level: namely, about 875 feet. It is difficult to account for these cols, except on the supposition that they represent the former courses of the two streams which descend the slope east of Bwlchyffin Farm. The upper valley of each stream is of mature aspect, but the lower part is a ravine indicating a change of base-level. The mature valley of the northern stream heads directly for the northern col, and that of the southern stream heads similarly for the southern col. If this explanation of the origin of the cols be accepted, the valley-floor to which the streams were graded must have entered the ancient Towy at a level of 860 to 870 feet.

There is a certain amount of concordance between the values deduced for the levels of the valley-floor to which these tributaries were formerly graded, and it is possible to reconstruct approximately the profile of that floor which represents the highest base-level observed in the area. The data are insufficient to enable one to draw an accurate profile; but a close approximation to it can be obtained by drawing a smoothed curve from above Nant Stalwyn to Bwlchyffin, so as to pass between the upper and the lower limits indicated by the profiles of the tributary streams. Further, by superposing on this curve either the profile of the existing river or the profile constructed from the logarithmic formula ($a=2\cdot4$), it is possible to obtain an approximate estimate of the base-level to which it is related. This appears to be about 580 feet above O.D. There is no doubt that detailed levelling of the minor tributary valleys would enable this most ancient valley-system to be reconstructed with considerably greater accuracy than is possible at present.

Thus, within the limits of the Towy valley, three distinct base-levels can be distinguished. The lowest or Llandovery base-level corresponds to the existing level of the sea; the middle or Fanog base-level, to which the valley between Nant Stalwyn and Fanog is due, now stands at about 400 feet above O.D.; while the highest or Nant Stalwyn base-level probably stands nearly 200 feet higher.

The Camddwr.—The upper part of the Camddwr profile, for $3\frac{1}{2}$ miles from its origin, is a markedly concave curve of considerable regularity, the level of the floor only departing occasionally from a smooth curve. In those places, as at Nant y Maen (1·4) and Ffrwd y Gamddwr (1·9), the river-channel lies in rock (see p. 580). At about 4·3 miles the gradient becomes steeper, and, between this point and Capel Soar (5·7), the profile is on the whole convex, and the channel lies mainly in rock. Below Capel Soar the profile is again concave, and the gradient diminishes downstream to Rhydtalog (6·7); below that place, however, the gradient steepens sharply. Near the junction with the Towy the Camddwr is graded with that river; but the profile of the middle reach between Capel Soar and Rhydtalog, if prolonged downstream, would join the Towy valley at a much higher level. It is not

possible to determine this level with any approach to accuracy, but rough limits can be obtained within which it must lie. The average gradient between 5·5 and 6·6 is about 90 feet per mile, and if this gradient persisted downstream to the mouth, the profile would stand at 734 O.D. or 50 feet above the present valley-floor. Since the gradient diminishes downstream, this figure must be regarded as a lower limit. On the other hand, the level at 6·6 or 1·8 miles above the mouth is 894, and the level at the mouth must be lower than this figure. Taking account of the rate at which the gradient is diminishing, the most likely value lies between 785 and 815 feet. It is probable, therefore, that the part of the Camddwr valley which lies between Capel Soar and Rhydtalog is related to the shelf in the Towy valley near the mouth of the river, which stands at about 800 feet O.D. This shelf is, in turn, related to the Fanog base-level. If the profile of the upper region of the Camddwr is prolonged, it would probably stand at a level of about 900 feet in the Towy valley, and this part of the valley is, therefore, related to the higher region of the Towy, or, in other words, to the Nant Stalwyn base-level. The assumption that within the Camddwr valley, as in the Towy valley, there are three distinct cycles of erosion, appears to afford the only adequate explanation of the physical features of the valley.

The Pysgotwr.—The profile of the Pysgotwr can be constructed for a length of $2\frac{1}{2}$ miles down to the point of rejuvenation, which is $3\frac{1}{2}$ miles distant from the Towy. The gradient curve constructed from the profile is approximately a rectangular hyperbola. An expression similar to that which was employed for the Towy may, therefore, be used to represent the profile.

From the gradient curve a is found to be $-1·6$. Various values of a above and below $-1·6$ were tried in the logarithmic expression, and compared with the curve. The results are given in Table III (p. 602), which shows also the differences between the calculated levels and those obtained from the smoothed profile. For comparison with the Towy results, the levels and gradients of the Pysgotwr at its junction with the Towy are recorded, on the assumption that the rivers met east of the Ystradffin gorge. The level which the Pysgotwr would have, if the rivers met at Towy Rocks, is also added.

It will be seen that all these values give fairly close agreement with the profile, the average difference ranging from 7 to 10 inches. In general, the agreement is closer for the lower part of the curve than for the upper. Although it is difficult to decide which value should be adopted in preference to the others, the values of a between $-1·4$ and $-1·6$ give the smallest average differences, both over the whole curve and in the lower part. The level of the Pysgotwr at its junction with the Towy ranges from 691·5 ($a=-1·8$) to 746·3 ($a=-1·2$) feet. Some of these values can be proved to be inadmissible, if the principle be assumed that the Pysgotwr (which is a smaller river than the Towy) has a higher

TABLE III.—SUMMARY OF RESULTS FOR THE PYSGOTWR.

x.	y obtained from curve.	$a=-1·2$	Diff.	$a=-1·3$	Diff.	$a=-1·4$	Diff.	$a=-1·5$	Diff.	$a=-1·6$	Diff.	$a=-1·8$	Diff.
2·1 [1]	1096												
2·3	1061	1058·9	−2·1	1058·4	−2·6								
2·5	1029	1028·2	−0·8	1027·6	−1·4	1027	−2·0						
2·7	1002·5	1002·0	−0·5	1001·6	−0·9	1001·1	−1·4	1000·5	−2·0	999·8	−2·7		
2·9	978·5	979·3	0·8	979·0	0·5	978·8	0·3	978·4	−0·1	978·1	−0·4	977	−1·5
3·3	941	941·1	0·1	941·3	0·3	941·4	0·4	941·5	0·5	941·5	0·5	941·8	0·8
3·5	925	925·1	0·1	925·2	0·2	925·4	0·4	925·6	0·6	925·8	0·8	926·3	1·3
3·7	911·5	910·3	−1·2	910·5	−1·0	910·7	−0·8	910·9	−0·6	911·2	−0·3	911·9	0·4
3·9	898	896·8	−1·2	896·9	−1·1	897·2	−0·8	897·3	−0·7	897·6	−0·4	898·2	0·2
4·1	885	884·3	−0·7	884·4	−0·6	884·5	−0·5	884·6	−0·4	884·8	−0·2	885·2	0·2
4·3 [1]	872·5												
4·5	861·5	861·9	0·4	861·8	0·3	861·6	0·1	861·4	−0·1	861·2	−0·3	860·7	−0·8
Sum of differences			7·9		8·9		6·7		5·0		5·6		5·2
Average difference			·79		·89		·74		·62		·70		·74
Difference between 3·3 and 4·5			3·7		3·5		3·0		2·9		2·5		3·7
Average do.			·62		·58		·50		·48		·41		·62
Gradient at the Towy .		23·1		26·1		29·3		32·8		36·4		44·4	
Level at the Towy (Towy=725)		746·3		739·7		730·2		721·9		712·6		691·5	

[1] These values, together with $x=3·2$, were used in determining the constants of the expression.

gradient at the junction than the main river. Only the values of a for the Pysgotwr which make the gradient of that river greater than 25 feet per mile (a for the Towy being assumed to be 2·4) need, therefore, be considered, and of these that in the last column ($a = -1·8$) certainly gives too straight and too steep a curve, all the points between 3·3 and 4·3 being above the profile and the last at 4·5 considerably below. One of the values of a between $-1·4$ and $-1·6$ must, therefore, be chosen; these indicate a level at the junction ranging between 730·2 and 712·6. The mean of these is 721·4, which may be compared with the level (724) determined from the Towy profile.

I am inclined to adopt as the most probable value that of $a = -1·6$. (The smallest average deviation from the curve is obtained with $a = -1·59$). It appears to give too low a level at the junction with the Towy; but it must be remembered that, before meeting that river, the Pysgotwr is joined by the somewhat larger Doethie, and the united rivers would undoubtedly have a lower gradient than either separately. With a value of $a = -1·6$, the level of the Pysgotwr at the mouth of the Doethie is 780·7, and, if the level of the Towy be assumed to be 725·6, the average gradient between that point and the Doethie is 32·4 feet per mile as compared with an average gradient of 36·4 if the Pysgotwr reached the Towy without being joined by the Doethie. This still leaves the gradient of the tributary higher than that of the main river.

The two rivers now join at the foot of the Towy Rocks at the point 7·36 measured along the Pysgotwr, or 12·8 on the Towy. The gorge of the Towy between Ystradffin and this point is of very recent aspect, as compared with the open valley of the tributary above the junction; and, as I showed on a previous page, the physical features suggest that the Towy was diverted into this course during, or at the close of, the Glacial Period, and that it formerly flowed along the wide valley south of Ystradffin, which is now floored to a considerable but unknown depth by glacial drift. It is clear that the Towy could not have been diverted in this direction, unless there previously existed a deep gap through the grey mudstone escarpment. The Pysgotwr above the Towy Rocks heads directly for this gap, and the northern slope of its valley is continuous with that of the gap (see fig. 6, p. 606). Moreover, the narrow ridge which extends northwards from the junction of the rivers is crossed by a slight col between the 500- and 600-foot contours. These features imply that the Pysgotwr formerly entered the Towy near Ystradffin, and that, in consequence of the rejuvenation of the drainage-system, it was diverted southwards nearly along the strike of the rocks, leaving a deep col through the escarpment. The diversion of the Towy by way of the col was probably brought about by glacial conditions. This suggestion is borne out by consideration of the profiles of the Towy and the Pysgotwr. If we assume that the ancient rivers met at the same point as the present rivers, there is a great discrepancy between the level of the

junction as determined from the two profiles. In the calculations made above, in which it has been assumed that they join beyond the Ystradffin gap at 7·9 miles and 12·3 miles from their respective sources the figures obtained for the level at the junction are closely accordant. On the other hand, at 12·8 the level of the Towy lies between 713 and 684 feet, according to the value of *a* adopted in the formula; and at 7·36 the level of the Pysgotwr ranges from 771 to 716. The lower value is, therefore, greater than the higher value given by the Towy curve, and, if we calculate the levels from the most probable values of *a* for these two profiles, we find 713 for the Towy and 739 for the Pysgotwr, which still leaves a considerable difference. If allowance be made for the flattening of the latter's profile after meeting the Doethie the discrepancy is increased. The profiles, therefore, support the evidence suggested by the physical features of a diversion of the rivers at this locality.

I was unable to obtain definite proof of two ancient base-levels in the main Pysgotwr valley or in the Doethie valley. There is a decided steepening of the gradient on the Pysgotwr at 2·4 miles from the source and a less pronounced change at 3·9; but these do not furnish evidence sufficient to establish the existence of a former base-levelled profile. Along the small stream Nant Cartrefle, which enters the Pysgotwr at Bryn Ambor (3·9), the Ordnance Surveyors ran a line of levels which allows the profile of that valley to be constructed. For the lower third of a mile of its course the stream is at grade with the present valley-floor; but, above that point, the valley flattens, becoming steeper again towards the source of the stream. There is here some evidence of a base-level about 70 feet higher than the present valley, which itself belongs to the Fanog base-level.

The profile of the Pysgotwr-fach which joins the Pysgotwr-fawr just below the point of rejuvenation is, however, difficult to account for, unless we assume the existence of a former base-level older than that represented by the mature valley of the latter. The point of later rejuvenation extends for about the same distance up this valley as along the Pysgotwr-fawr, and the ravine has been developed in the floor of a wider valley comparable with that of the adjoining stream. This portion is, however, very short, and is separated from the larger and higher portion of the valley by another ravine. Above this ravine the valley opens out; its longitudinal and transverse profiles are those of a thoroughly mature valley. It appears to grade, however, with a level 70 to 90 feet above the base-levelled floor of the Pysgotwr-fawr. The higher base-level indicated by these tributaries agrees with the Nant Stalwyn base-level of the Towy, and appears to suggest that only the part of the Pysgotwr-fawr above 2·4 belongs to it.

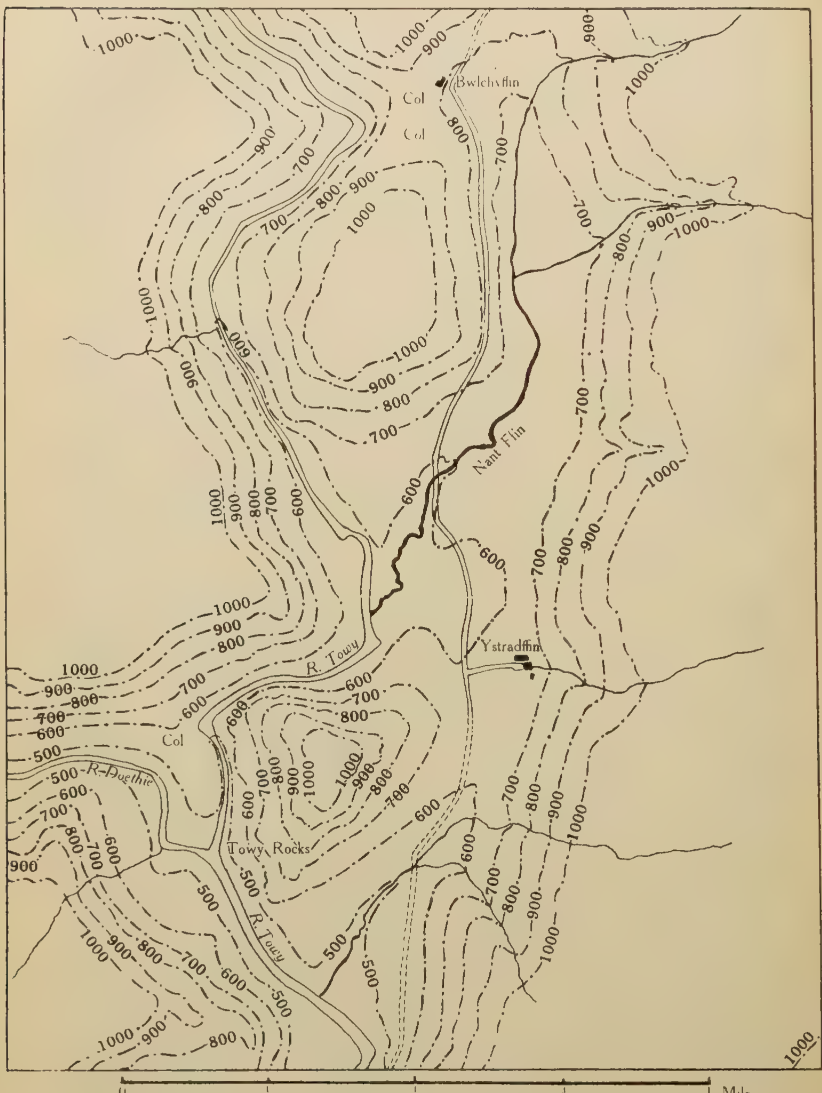
The Cothi.—I was unable to find an opportunity for levelling the Upper Cothi valley, and only a few heights on the

valley-floor were determined with the help of a theodolite. These do not give a sufficient number of points to enable a reliable curve to be constructed. The profile is concave, but relatively flat, and from near the origin to 2·2 the gradient diminishes very slowly downstream. If the gradient remained the same below 900 (2·2) as it is between that point and the 1000-foot contour-line, the level at the junction with the Towy would be 587 feet. As no allowance is made for a flattening of the profile downwards, this is obviously a minimum figure. Some idea of the degree of flattening can be obtained from the position of the rock-floor of the beheaded valley in the col at Bwlchyrhiw. This floor is about 30 feet above the straight profile, and at the mouth of the valley would be at least 90 feet above, assuming that the flattening is proportional to the distance. In reality, it would be higher, since the diminution of gradient downstream is progressive. The level at the junction may then be estimated to have been at least 677, and was probably somewhat higher. Since the level of the Towy at that point has been calculated to be 680, it is obvious that there is close correspondence between the estimated levels of the two ancient valleys at their junction. The results, though admittedly crude, are consistent with those obtained from the adjoining valleys, and with the physiographical evidence that the Upper Cothi originally drained into the Towy above Rhandirmwyn.

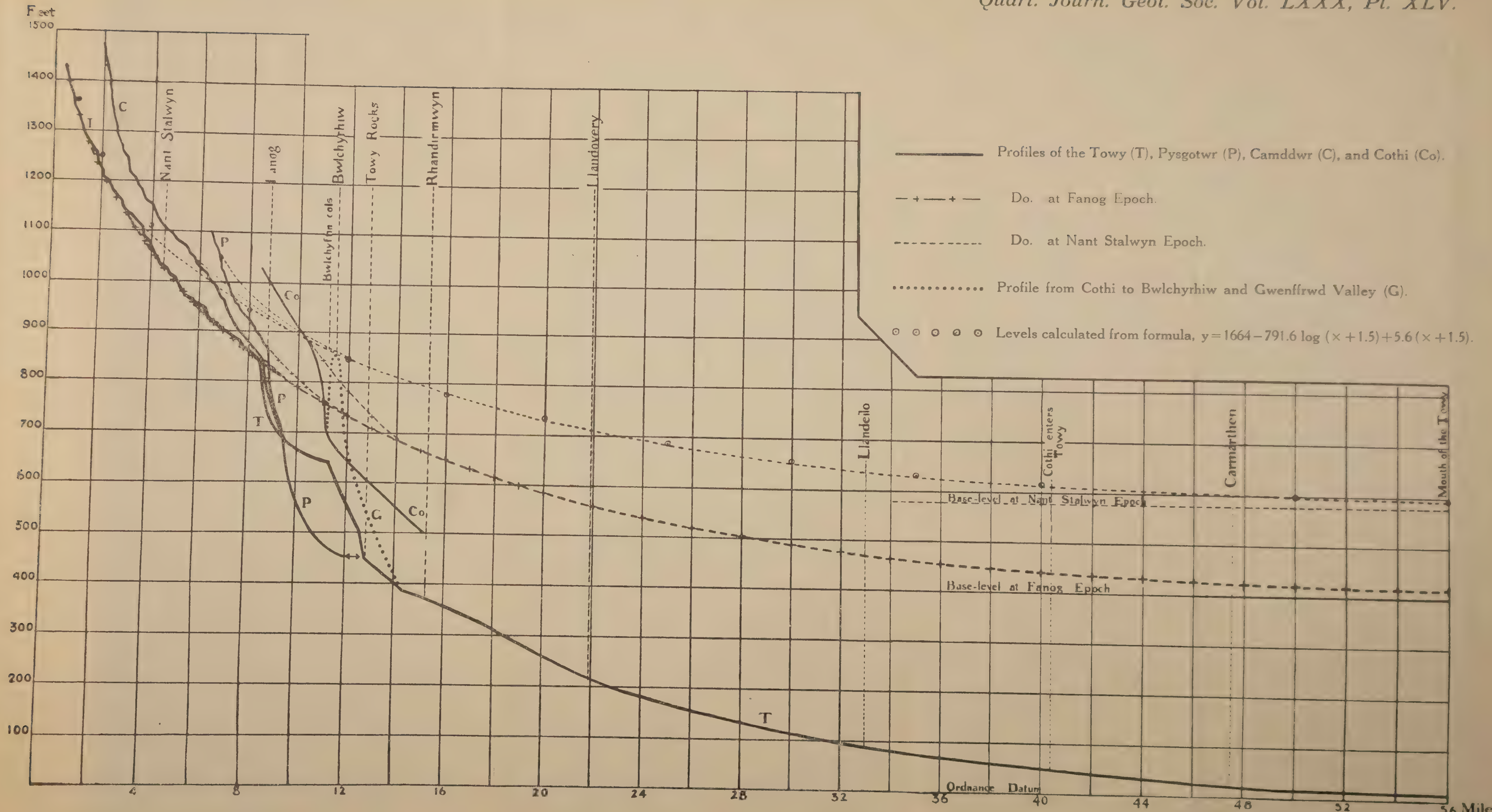
There is no evidence in the Cothi valley of the Nant Stalwyn base-level, and the whole of the ancient valley appears to have been fashioned in relation to the Fanog base-level.

The physical features of the Towy valley and its tributaries thus reveal the former history of the drainage-system in some detail. The uppermost portions of most of the valleys still retain considerable traces of the form which they attained during the late stages of the Nant Stalwyn period of base-levelling. This period appears to have been a prolonged one, and the valleys reached a late-mature stage of development. It was followed by a lowering of the base-level due to general uplift of the region, whether or no accompanied by tilting cannot at present be determined. Most of the mature valleys were destroyed during the Fanog period of base-levelling to within a few miles of their source. Towards the close of this period the lower portions of the valleys again attained a mature form. Then followed a second uplift, with consequent lowering of the base-level. A second excavation of the lower parts of the valleys gave rise to their present forms, except in so far as they have been modified by some glacial erosion and deposition. Erosion has already proceeded so far, that, for about 40 miles above its mouth, the Towy valley has attained for the third time a mature stage which is related to the existing Llandovery base-level. The points on the Towy and its tributaries where the last remnants of the Nant Stalwyn base-level can be recognized lie on an almost straight line drawn from above Nant Stalwyn to near Bonborfa on the Pysgotwr. This line,

Fig. 6.—*Map of the district near Ystradffin, to show the relations of the Towy and Doethie Valleys.*




CONTOURED MAP OF THE TOWY BASIN ABOVE RHANDIRMWYN.
indicates the water-parting between the Towy and the Teifi and Wye Basins.
indicates the origin of the longitudinal profiles shown on Pls. XLIV and XLV.
The figures along the streams indicate distances from the origin measured along the valley floors. Land above 1,500 feet is stippled.
SCALE: One inch = One mile.
0 1 2 3 Miles
Wye Basin
Teifi Basin
Nant Stalwyn
Ffrwd y Gamddwr
R. Camddwr
R. Towy
R. Doethie
R. Irfon
Bonborfa
R. Pysgotwr
R. Pysgotwr-fach
Bryn Ambor
Fanog
Henfaes
Trawsnant
Bwlchyffin
R. Gwenffrwd
Garthynty
R. Cothi
Towy Rocks
Ystradffin
Bwlchyrhiw
Crugiau Ladies
RHANDIRMWYN



Feet
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
4
8
12
16
20
24
28
32
36
40
44
48
52
56 Miles.
Nant Stalwyn
Fanog
Bwlchyfan cols
Bwlchyrhiw
Towy Rocks
Rhandirmwyn
Llandovery
Llandeilo
Cothi enters Towy
Carmarthen
Mouth of the Towy
T
C
P
Co
G
Base-level at Nant Stalwyn Epoch
Base-level at Fanog Epoch
Ordnance Datum
Profiles of the Towy (T), Pysgotwr (P), Camddwr (C), and Cothi (Co).
Do. at Fanog Epoch.
Do. at Nant Stalwyn Epoch.
Profile from Cothi to Bwlchyrhiw and Gwenffrwd Valley (G).
Levels calculated from formula, y = 1664 − 791.6 log (x + 1.5) + 5.6 (x + 1.5).

if prolonged, would pass beyond the head of the Cothi valley and thus confirms the conclusion previously drawn that the old valley belongs to the Fanog period of base-levelling. It is not improbable, however, that the surface of the plateau near the heads of the valleys is mainly the result of erosion during the oldest or Nant Stalwyn period of base-levelling, and that it has not been seriously modified by subsequent erosion. It may, therefore, be of high antiquity. No dates can be assigned from any evidence in the upper part of the Towy drainage-system to the periods of base-levelling and of uplift; but it is hoped that some clue to their age will be obtained when the lower part of the Towy basin has been examined.

The method described above of reconstructing an ancient drainage-system appears to lead to results of considerable interest, and there is little doubt that a higher order of accuracy could be attained if, in addition to the more important valleys, the smaller tributary valleys had been similarly levelled.

It is a matter of regret that the Ordnance Survey has not carried out a series of levels along the main valleys of the country. If such levels were available, a vast amount of information would be readily accessible regarding the physical history not only of this region, but of other parts of the British Isles.

EXPLANATION OF PLATES XLIII–XLV.

Plate XLIII.

Contoured map of the Towy Basin above Rhandirmwyn, on the scale of 1 inch to the mile, or 1 : 63,360.

Plate XLIV.

Profiles of the Towy Valley and its principal tributaries above Rhandirmwyn. Scales: horizontal = 1 inch to the mile, or 1 : 63,360; vertical: 1 inch = 100 feet.

Plate XLV.

Profiles of the Towy, Pysgotwr, Camddwr, and Cothi. Scales: horizontal = 5 miles to the inch, or 1 : 316,800; vertical: 1 inch = 250 feet.

Discussion.

Dr. A. Morley Davies expressed his great interest in the paper. The two uplifts of which evidence had been adduced were on a much larger scale than the post-Glacial uplifts recognized in the Thames Valley, and must evidently date back to at least Pliocene time. This raised the question as to possible diversions of the river-system, and he enquired as to the probability of the Towy having originally flowed through the Llandeilo wind-gap.

Mr. G. W. Lamplugh remarked that several valleys in the Isle of Man showed features similar to those described. He suggested that the position of the midway gorge was usually in part determined by the space required as a gathering-ground before the stream gained sufficient volume to become effective under

present conditions of diminished precipitation. In drift-cumbered upper basins the feeble headwaters were frequently incapable of shifting residual boulders, which accumulated and protected their beds. The Author's method of research was likely to yield great results, but the factors involved were numerous.

Dr. J. A. Douglas congratulated the Author on his paper, and said that it was not merely of interest to those who possessed an intimate local knowledge of the district, but involved principles that were of world-wide application. The Author's description of the rock-steps of the Towy valley reminded the speaker of certain high-level valleys in the Peruvian Cordilleras, which exhibited a similar series of rock-steps. He had formerly been led to consider these as phenomena due to glacial erosion; but this paper had suggested a new line of reasoning, and he now felt tempted to regard them as marks of successive uplifts passing one after the other up the valleys in question. Eventually, it might be found possible to correlate these with the raised beaches of the coast. These rock-steps or sudden changes of grade would work their way backwards from mouth to source up main and tributary valleys alike. The greater erosive power of the main stream, however, would tend to obliterate them more rapidly than in the tributary valleys, and it was, therefore, in the latter that their more complete record would be preserved.

Mr. S. W. Wooldridge thought that the paper would re-awaken interest in river-problems in this country. The work of the late Joseph Bassett had shown that important results might be expected from a close scrutiny of physiographic profiles. Nevertheless, British workers had been slow in following the lead given to them by Prof. W. M. Davis in his well-known publications, now thirty years old. Prof. Davis had maintained that the British area yielded evidence of two distinct cycles of denudation, the first culminating in peneplanation. The present Author's conclusions seemed compatible with this suggestion, although they could scarcely be said to bear directly on the question.

It was a significant fact that a change of base-level, amounting to about 400 feet, had affected not only Central Wales, but regions so widely separated as Cornwall, Aberdeenshire, and the London area. Hence it seemed likely that rejuvenation was caused by eustatic movements of sea-level, rather than by crust-warping.

The existence in the area studied of hanging tributaries, the formation of which antedated the period of glaciation, afforded an interesting confirmation of Prof. J. W. Gregory's contention that certain hanging valleys in Arran and elsewhere were not caused by glacial over-deepening. It was becoming increasingly clear that the importance of the glacial factor in the formation of such valleys had been overestimated in the past.

The Author replied that the amounts of the uplift responsible for the rejuvenation of the district were stated in the paper to be about 400 feet and 580 feet respectively. It was not possible, from the evidence in the region studied, to assign any date to the

periods of the uplift. It was tempting to correlate the later uplift of 400 feet with that recognized in Devon and Cornwall; but, owing to the difference in the length of the valleys affected by rejuvenation in the two regions, it was premature to assign them to the same period of uplift. With regard to the course of the Towy in the lower part of the valley it was possible, as Dr. Davies suggested, that the river formerly went through the wind-gap at Llandeilo; but the distance to Carmarthen Bay by either course would be about the same, and would not sensibly affect the change of base-level indicated by the profiles of the upper part of the valley. There are, below Llandeilo, other wind-gaps which are as yet unexplained: they stand opposite to several streams, which drain into the Towy valley from the north, and appear to indicate that at one period the drainage of the region was mainly from north-west to south-east across the trend of the present Towy valley. These features require further investigation.

It was not surprising to learn from Mr. Lamplugh that the features observed by him in the Isle of Man were very similar to those of Central Wales, as (in all probability) the physiographical history of the two regions was somewhat similar. With regard to a large volume being necessary before a stream can start cutting into its channel, this did not seem to be borne out in the district, since quite small streams have cut ravines and glens which are more or less proportional to their size. The probability of the ancient valleys having been eroded under climatic conditions different from the present was discussed in the paper, and the conclusion reached that, while the rainfall may have been smaller, the load of the streams probably consisted of materials of finer grain: and, the effects of these two factors being in opposite directions, it was assumed provisionally that they cancel one another.

The evidence that the tributary valleys were, in the main, of pre-Glacial age seemed to be unquestionable; and, although the main valley has been glaciated, the glacial striæ point in places across the valley, so that probably but little erosion was brought about by glaciation. In general, if a series of rejuvenations followed one another up the main valley, one might expect to find corresponding rock-steps in the tributary valleys; and, if the tributary streams are small in proportion to the main stream, the rock-steps might persist after those in the main valley had been obliterated.

The possibility that regional tilting of the area had occurred was discussed in the paper, but evidence for this must be sought in a lower part of the valley. If it were found that an uplift of about 400 feet could be established in widely different parts of the country, this seemed to point to eustatic movements. If the movement were of this kind, the reconstruction of this and other drainage-systems by the method suggested could be carried out with more confidence.

GENERAL INDEX

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